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Describes a systems approach to instruction and various types of teaching machines, accompanied by numerous sketches of some of the machines. Discusses concepts and techniques of the programing process and research findings related to teaching machines. Although the author views this research as more provocative than definitive, he offers the judgment that teaching machines may eventually provide the basic data for a new theory of teaching, the missing counterpart of the theory of learning. "In effect," he states, "the teaching machine is an educational laboratory. . . . The machine can provide information about methods of teaching free of uncontrolled variations due to differences among teachers. Once the basic variables in the instructional process are identified, they can be studied in relation to social and personality factors."

This monograph is an outgrowth of a University of Illinois project supported in part by the Cooperative Research Program of the Office of Education. Includes a bibliography of approximately 400 titles.

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Teaching by Machine

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TEACHING BY MACHINE

Lawrence M. Stolurow
University of Illinois

U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Abraham Ribicoff, *Secretary*

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Foreword

THIS MONOGRAPH is an outgrowth of a research project currently being conducted at the University of Illinois under the direction of Dr. Lawrence M. Stolurow, Professor of Psychology. In the course of the project, "Principles for Programing Learning Materials in Self-Instructional Devices for Mentally Retarded Children," a wealth of information has been collected that pertains to machine systems, types of teaching machines, concepts and techniques of the programing process, research findings related to teaching machines, and the impact of machines on research on learning.

The exploding world population, the need for specialization, and the changing science and technology of our current society are some of the major factors producing demands for a change in traditional practices to provide more economical and efficient solutions to educational problems. Therefore, the purpose of this monograph is to examine the potentialities of some of the auto-instructional materials as a possible resolution of some of today's critical problems in education. Dr. Stolurow also reviews some of the basic concepts and implications of what promises to be a "new look" in education.

Although the project upon which this monograph is based is being supported by the Cooperative Research Program, most research projects related to auto-instructional materials supported by the U.S. Office of Education come under the auspices of Title VII, "New Educational Media," of the National Defense Education Act of 1958. At the present time 27 research projects dealing with auto-instructional materials and techniques are being supported by the New Educational Media Program. Federal funds totalling approximately $1.87 million have been obligated to bring these research projects to completion.

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Director,
Educational Media Branch

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Director,
Cooperative Research Branch

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CHAPTER I

Current Instructional Problems

Crossroads in Education

The "population explosion" probably will have its greatest impact upon the education system. The resources required to cope with critical problems, particularly teachers and schools, are not only expensive but also slow in becoming available in needed numbers. Even when population growth was at a slower rate, these resources lagged. Eurich (1960),[1] for example, has pointed out that the deficit in our production of teachers and classrooms has continued at a rate that is disgraceful, considering the demonstrated creativeness of the United States in other areas and its overall resources.

The special problem of the United States is particularly pressing. However, the problem in other countries may be as great or even greater; for hundreds of millions throughout the world are illiterate. Great discrepancies in literacy, and correspondingly, in standard of living, should not go on without attention. Educational aid may be even more important than economic aid to underdeveloped areas, for with education these peoples would become more self-sufficient and productive. The complex tools and equipment provided in today's form of aid must be understood by the people who use them in order to be used effectively and maintained for efficient and enduring use. Thus, for material-giving to be effective, information and idea-giving should be equal or more generous.

Throughout the world twin problems exist: (*a*) Illiteracy, and (*b*) the need for technical knowledge to accelerate the rate of self-development through the use of complex new tools.

Illiteracy needs to be attacked today. Even in countries where the literacy rate is relatively high, however, the demands for education are increasing and the struggle to maintain present literacy levels will become more, not less, difficult (Unesco, 1957).

---

[1] References in parentheses throughout the monograph indicate author and year of publication, as listed in the section beginning on page 151.

The exploding world population, while exceedingly important, is only one of the intense pressures creating the demand for a rapid and economical answer to the problems of education. The exponential rate at which new knowledge is being generated is a second factor. In practically every field, but particularly in the sciences, new knowledge is being produced more and more rapidly each year. To cope with this state of affairs, most professional scientists have become increasingly specialized. With the available teaching methods and facilities, specialization also seems to be the only solution for teachers.

The changing science and technology of our current society, therefore, is a third major factor producing demands for an economical and expeditious solution to our educational problems. Today vocations are changed in many important ways during each man's productive years, whereas in the not too distant past, it was possible for a man to learn a trade and, after an apprenticeship, look forward to practicing his trade without ever having to learn anything new. The society of 50 years ago considered the artisan who continued to work with a particular set of procedures, productive and efficient. There was no question of his remaining gainfully employed. Now, however, occupational change is a fact of life; trades are quickly modified, and almost overnight new processes and new products make acquired skills obsolete. It is no longer possible, in the more highly developed countries, for a man to stop learning. Furthermore, the men and women who learn these trades are living longer. The increased number of older persons is, by itself, a significant factor increasing the requirement for education.

Just what can be done about these urgent demands for education? Attempted solutions patterned exclusively after current practice will not solve the problem; not only do they take too long, but also the resources they require—human teachers—are not available for the task. Furthermore, even if teachers could be made available in the needed number, the cost of providing them by today's means alone would be crushing.

A Solution to Educational Crisis

The impact of machines on industrial, agricultural, and research productivity has been dramatic. Machines may make a similar, or even greater, impact upon education. Instructional devices are not new to education; the ones available, however, have not increased the teacher's efficiency enough to cope with the rapidly expanding need for instruction. The resolution of this paradox may come about by a new concept of instruction as a communication and control process. From this point of view a new type of educational device, the teaching machine, is emerging. It is a system providing critical functions not now implemented in the familiar instructional device or teaching aid. This new system makes it possible to accomplish in the absence of a "live" teacher some of the critical functions of instruction through auto-instruction or automated teaching.

The purpose of this monograph is to examine the potentialities of auto-instruction or automated teaching as a possible solution to some of today's critical problems in education. This will be done by first looking at some basic concepts in what promises to be the "new look" in education. These concepts are briefly covered in the next chapter. The later chapters deal with the more salient implications of this new look.

CHAPTER II

A Systems Approach to Instruction

TODAY, more than ever before, efficiency in instruction should be paramount. In the past, many approaches have been proposed, but they have been too limited in nature. In fact, from one point of view they have been aimed at treating the symptoms rather than the basic problem itself; for example, manipulation of the teacher/student ratio, lengthening the school year, or providing the teacher with a bewildering array of so-called aids. Genuine instructional efficiency might be achieved, however, by a reexamination of instruction itself rather than by attempts to patch up supporting activities. This reexamination might be aided by a new point of view, such as the one presented here, which proposes the integration of learning and instruction as provided by the systems concept, coupled with a direct effort to implement the emerging modern learning theory and results of current research by building them into the instructional system.

INSTRUCTION AS COMMUNICATION AND CONTROL PROCESSES

Instruction according to this point of view is the process in which a teacher presents subject matter to a learner so that he responds to it in a way that enables the teacher to determine the next item of information to be presented. We define the primary objective of instruction as the modification of the learner's responses to satisfy the teacher's criteria. In other words, the teaching-learning process can be viewed as communication and control taking place between the components of a system. In this case the system is composed of a teacher, a program of instruction, and a student, all in a particular pattern of interaction.

Typically the teacher is the source of the communication and the controlling mechanism. However, he is ordinarily working with a group of students and thus in effect responsible for implementing a large number of communication-control procedures, one per student; a most difficult task. For all practical purposes, a teacher, at best, can work only intermittently with each student; whereas, for optimum efficiency, continuous interaction is necessary. The problem is to find a way in which continuous communication and control can replace occasional communication and control, since it is impossible to provide each learner with a private teacher, to achieve educational efficiency with economy.

To accomplish this the classroom teacher must perform at least two interrelated but separable functions: (*a*) the planning of instruction, and (*b*) the implementation of instruction. The former will continue to be the chief province of the teacher. However, [illegible] proposed that the latter can be accomplished automatically, at least in part, by properly designed devices currently referred to as teaching machines, automatic tutors, or auto-instructional devices.

A teaching machine is defined here as a mechanism that presents information to a student and controls his behavior in a predetermined interacting relationship. A teaching machine is substituted for the live teacher who normally implements the instruction (see fig. 1). This interaction depicts only the implementation activities, not the planning activities. Looking at the problem of instruction in this way seems to give an advantage over prior conceptions, for it is possible to take the planned instruction of a single teacher and implement it for a large number of individual students in accordance with current concepts in regard to the best conditions for learning and instruction. This modification results in a man-machine system, i.e., a learner, a program, and a teaching machine. The problem of efficiency now

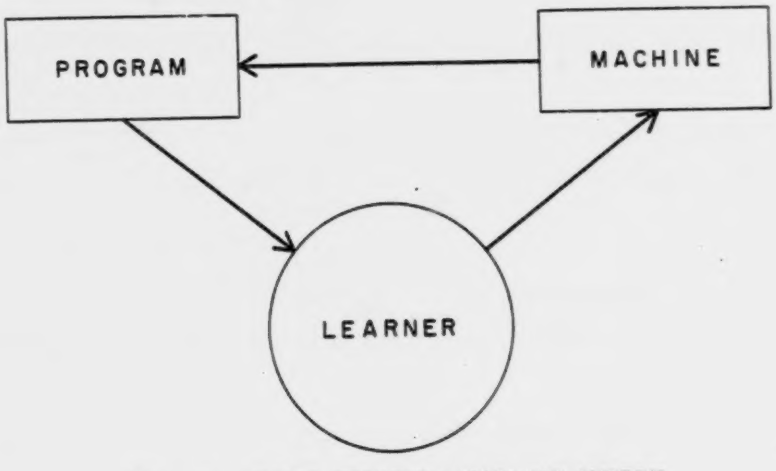


Figure 1.—BASIC TEACHING MACHINE SYSTEM

becomes one of optimizing man-machine functions, the basic problem of systems engineering.

Two problems arise: one, to determine what specific functions are to be optimized; the other, to determine the best way to optimize. Knowledge of what to optimize comes from an analysis of the learning process. This is achieved by the examination of the learner's errors, departures from the teacher's criterion. If improvement is to be produced, sources of errors must be detected and misunderstandings must be corrected by means of established principles, laws, and relationships. Here the psychology of learning and instruction can provide guidance.

The teacher's criterion identifies the specific performance to be achieved. The critical conditions of learning indicate that this is achieved by immediate knowledge of results once the learner has responded to a cue. Thus there are at least three critical system functions: (*a*) The cue function provided by the program of instruction, i.e., the stimulus to which each criterion response is attached; (*b*) the motivation function, i.e., eliciting the desired performance; and (*c*) the feedback function, i.e., providing immediate knowledge of results.

In order to implement the critical psychological and educational notions in actual instruction it is necessary to make some additional distinctions among components and functions of the training system. In doing this it becomes possible to write the requirements and specifications for a teaching machine.

The requirements have specific implications for engineering design. They are not all-inclusive but constitute what might be considered a set of critical requirements necessary to efficiently implement part of the instruction process by a teaching machine.

CRITICAL REQUIREMENTS OF A TEACHING MACHINE

Ten requirements appear to be critical:

1. **Display (presentation)**
2. **Response**
3. **Pacing**
4. **Comparator**
5. **Knowledge of results or feedback**
6. **Collator-recorder**
7. **Selector**
8. **Library or storage**
9. **Programing**
10. **Computor**

The above requirements and their relationships are illustrated in figure 2.

1. *Display.*—The presentation requirement illustrated in figure 2 is fulfilled by the display unit. Through the use of appropriate communication channels—visual, auditory, tactual, or a combination—

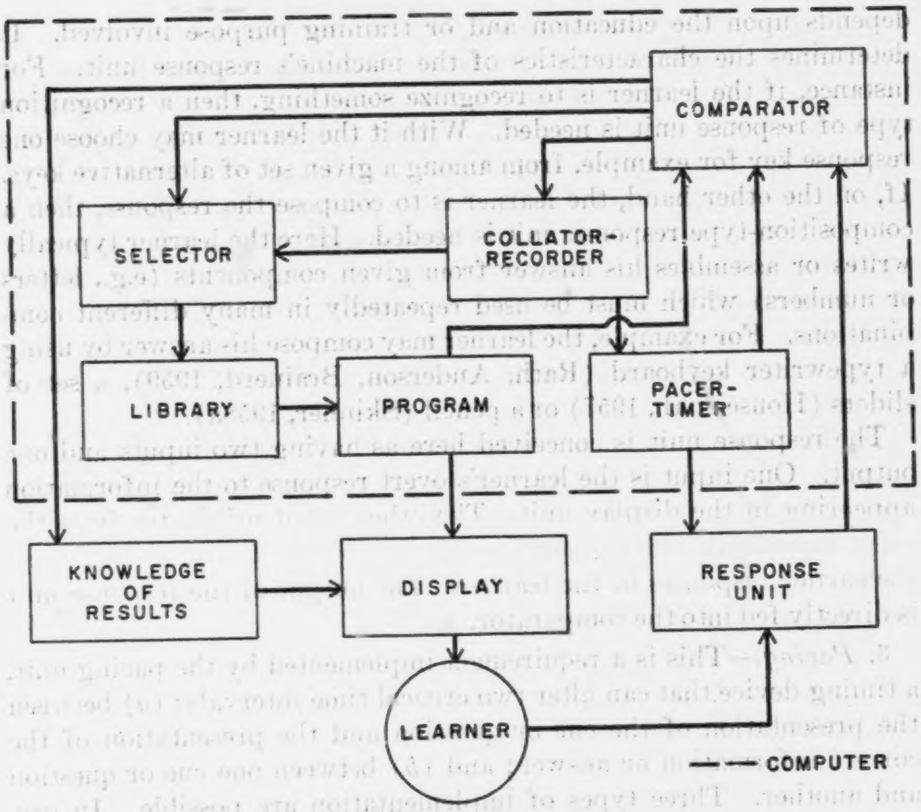

COMPARATOR
SELECTOR
COLLATOR-RECORDER
LIBRARY
PROGRAM
PACER-TIMER
KNOWLEDGE OF RESULTS
DISPLAY
RESPONSE UNIT
LEARNER
COMPUTER

Figure 2. ADAPTIVE TEACHING MACHINE SYSTEM

the subject-matter information is presented to the learner in accordance with the nature of the material to be taught. Typically, some critical information is followed by a question or a cue to which a response is to be made; this is particularly true with courses in language, mathematics, physics, psychology, etc. In the case of complex skills such as the monitoring and decision processes related to the operation of an oil refinery or an atomic reactor, driving a car, or flying an aircraft the presentation function takes on a special significance because of the necessity for simulating, with fidelity, the important environmental conditions.

The display unit as conceived here has two inputs and one output (see figure 2). One is the program input, which precedes response; the other is the knowledge-of-results input, which follows response. The output from the display is, of course, directly received and interpreted by the learner.

2. *Response.*—This is a requirement for a unit that implements the response initiated by the learner. The form of the learner's response

depends upon the education and/or training purpose involved. It determines the characteristics of the machine's response unit. For instance, if the learner is to recognize something, then a recognition type of response unit is needed. With it the learner may choose one response key for example, from among a given set of alternative keys. If, on the other hand, the learner is to compose the response, then a composition-type response unit is needed. Here the learner typically writes or assembles his answer from given components (e.g., letters or numbers) which must be used repeatedly in many different combinations. For example, the learner may compose his answer by using a typewriter keyboard (Rath, Anderson, Brainerd, 1959), a set of sliders (House et al., 1957) or a pencil (Skinner, 1958a).

The response unit is conceived here as having two inputs and one output. One input is the learner's overt response to the information appearing in the display unit. The other input originates from the pacer-timer unit. It is a secondary input, in that it is dependent upon the earlier responses of the learner. The output of the response unit is directly fed into the comparator.

3. *Pacing.*—This is a requirement implemented by the pacing unit, a timing device that can alter two critical time intervals: (*a*) between the presentation of the cue or question and the presentation of the correct information or answer; and (*b*) between one cue or question and another. Three types of implementation are possible. In one, fixed-interval pacing, both intervals are fixed and preset into the machine. In another, variable-interval pacing, both intervals are dependent upon the learner's rate of response. In the third, mixed-interval pacing, the first interval is determined by the learner but the second one, the inter-item interval, is fixed and preset into the machine.

In addition, pacing can relate to the rate at which information is presented; for example, with a motion picture or tape recorder the learner can adjust the rate at which the images are shown or the speech sounds follow one another (Enc and Stolurow, 1960; Fairbanks, Everett, Jaeger, 1954). This may be called information pacing.

4. *Comparator.*—The comparator requirement is implemented by a comparator unit. This unit either automatically analyzes the learner's response by comparing it with the appropriate correct response stored in the machine, or it allows the learner to make this comparison himself. The comparator unit illustrated in figure 2 is conceived as having three inputs and three outputs. The first input comes directly from the response unit, which channels response information into the comparator. The second input comes directly from the program, which contains the correct answer to the question asked of the learner. This is the criterion used in effecting the comparison. The

third input originates from the pacer unit and is used whenever the educational objective has a timing requirement. The result of the integration of the three inputs goes through three output channels feeding respectively into the knowledge-of-results (or feedback) unit, the collator-recorder unit, and the selector unit.

5. *Knowledge of results or feedback.*—This is a requirement for communicating to the learner the correctness or incorrectness of his response. The most simple and common type of feedback occurs when the learner is allowed to compare his response with the criterion or correct response; in that case it may be a biproduct of the comparator function. However, the feedback process may be implemented by the machine—a particularly desirable feature if the learner is a young child or low in ability. For instance, the Osler (1960) machine delivers a token when the learner is correct and nothing when he is incorrect.

If the machine, rather than the learner, fulfills the comparator requirement, then knowledge of results about the correctness or incorrectness of a response can be implemented by different means which do not exclude one another; for instance, a simple mechanism that provides a "yes" or "no" answer (e.g., a green light for a correct answer, a red light for an incorrect answer, or a buzzer sound for a wrong or right response). Simultaneously and/or separately, knowledge of results can be given more extensively through the event sequence in the program itself. For instance, if the learner selects the correct alternative among a preprogramed set of choices, he is told that he was correct and given additional information. If he selects an incorrect alternative, however, he is told that he was incorrect, the machine provides corrective and supplementary information, and he then makes another choice. This process continues until the correct choice has been made. Feedback implemented by the program in this way is thus sensitive to individual differences in learning. It is often preferred over the simple right/wrong feedback when the implementation of the respective functions takes the same amount of time; otherwise an immediate right/wrong feedback is preferred. Consequently, the knowledge-of-results unit may or may not be a separate unit in a teaching machine system. It is shown as a unit in figure 2 to make this very important requirement salient.

6. *Collator-recorder.*—This is the requirement to measure and record the learning process. It is implemented by either a collator or a simple recorder unit. Both collect such data as the number of errors, the type of error, the time intervals required for response, etc. The recorder may simply accumulate these data; however, a collator

records them in such a way that each item is collated with the part of the program to which it pertains. The data can be made available to the teacher, the learner, the machine, or any combination of them. Typically, the data will be used post facto by the teacher-programer to diagnose the learner's special difficulties. It also is useful in making improvements in the instructional program. The most sophisticated teaching machines use data collated by the recorder through the selector unit to decide upon the next item of information to present to the learner. When equipped with timing data, the machine also may decide upon the subsequent rate of presentation.

As conceived here and illustrated in figure 2, the collator-recorder unit has one input and two outputs. The input comes from the comparator unit; it provides "out of tolerance" (departure from criterion) information about the learner's responses. One of the outputs goes direct to the selector unit and determines the next item of the program; the second, used whenever there is a pacing requirement, determines the rate of change of the display and/or response units.

7. *Selector.*—This requirement exists whenever there are alternatives in the program presented to the learner. The selector unit selects the next item in the program. It can vary in operational complexity. The simplest form is binary: there are at least two possibilities for the next display, depending on whether the response is right or wrong. Following a wrong response there is either no change in the display or else a previous item in the program is selected. A more elaborate selection requirement exists when finer distinctions are to be made among responses. For example, selection may depend upon the attainment of a particular level of proficiency, e.g., two successive correct responses. This uses the accumulated data of the recorder to determine the next item of the program. In this case, the direct inputs from the comparator and the recorder are indispensable. Indeed, it is through their information channels that the machine can automatically exclude from the program the items to which the learner responded correctly so that on the next trial, for a particular performance criterion, the learner sees only the items he missed. This is the adjusted-learning method originated by Woodworth (1938); it can require different criteria of mastery at different stages.

Selection also can be based upon response-pattern interpretation. A combination of several response characteristics could equally be used in the course of the selection process; for instance, latency and correctness of answers. The selector unit has two inputs and one output. One input is from the comparator. This, the more basic one, provides the necessary information for even the binary selection process. Another input to the selector can originate in collator-recorder units; it is used whenever selection is based upon response-pattern interpretation. In this case the machine selects the next item on the basis of the previous response history of the learner rather than just his latest response.

8. *Library.*—This requirement, for the storage of information to be used as needed by the learner, is implemented by a library unit.

Important features of the library are its capacity, access time, and form, or medium of storage. Capacity may vary from approximately five items (Stolurow and Porter's device) to a very large capacity numbering in the thousands as in the Crowder Autotutor (1959) and the IBM (Rath et al., 1959) 650 Computer. Most existing devices have low or only moderate capacity; for example, the Subject Matter Trainer stores 20 items, Skinner's machine has 29 items per disc, Peterson and Pressey's devices accommodate only a small number of items. Somewhat larger in capacity are the MASTS, AUTOMASTS, (Bryan et al., 1954), and Visitutor (Blyth, 1960b). The Scrambled Book (Crowder, 1959), the Programed Textbook (Homme and Glaser, 1959), and the Cut-Back Page Book (Stolurow) are printed devices which can accommodate a still larger number of items.

The access time to a selected item is an important feature of the library, for it determines the speed with which information can be presented. The most critical thing in this respect is the access time of the feedback. As the need for storage becomes large, the access time becomes more of a problem. Film devices usually are set for 24 frames per second for motion sequences; however, the exposure time will often vary for different items when roll film is used to present stills. On the other hand, slides have the advantage over roll film for still presentation, for they permit a more uniform access time over a larger number of items.

Access time is to some extent related to the storage medium, which can be (*a*) printed paper, (*b*) film, or (*c*) electrical charge, as in a computer. Examples are card devices (Briggs, 1958); paper discs, (e.g., MASTS, AUTOMASTS Bryan, et al., 1954); disc devices (Skinner, 1954); and the Subject-Matter Trainer. Printed sheets are used in Porter's device (1958 c), in Pressey's (1950) machine, with the Peterson (1930) Chemo-card, the Ferster and Foringer machine (1958), and the 1984 machine of Teaching Machines, Inc., Albuquerque, New Mexico. The library may be composed of different materials, and the information may be available upon demand for either discrete or motion sequences. Demand is created whenever a response is made; the relationship between the response and the criterion as determined by the comparator is the cue to the selector mechanism to select particular items of information from the library for display to the learner.

9. *Programing.*—This is the requirement for a sequence of items; however, the particular ways in which items are sequenced can be quite different. A sequence can be entirely predetermined—a linear or noninterpretive program—or it can be determined as the learner makes his responses—a branching or interpretive program. Regardless of type, the program is a subject matter organized according to some plan and/or sequenced according to a set of "programing rules" (see chs. v and vi).

The two basic types are the result of specific methods of implementing a program. They have different implications for machine design. The program is the library output displayed for the learner; thus, as a system unit it has one input and two outputs: (*a*) to the display and (*b*) to the comparator.

With a linear program there is no variation in the initial sequence in which information and questions are presented. However, it may be *selective* in that the different errors made by learners determine whether or not items are dropped out. This is the adjusted learning method (Woodworth, 1938). With this type of program (selective linear) the library contains but one program; and every learner sees all of it initially and selected portions more than others. This type of program places minimal demands upon the selector unit, which can be so simple that it merely takes each item from the library in the order in which the items are stored there. The comparator function also is simplified in this case, for it merely has to be designed to make a binary decision: (*a*) to select for later use, or (*b*) to reject for later use. If the adjusted learning method is not used, no selection is made at the time the learner responds; however, the program is preselected and stored in the library in the order to be used.

Unlike the linear program, the branching program is responsive to individual differences in need for supplementary information. There are differences in the material seen (or heard) by learners on first experience with the program, and much more is prepared and stored in the library than any one learner will see even initially. Two basic procedures are followed: (*a*) Alternative "routes" are incorporated into the program, and (*b*) more than one type of error is provided for, to permit finer interpretations and more selective routing. Usually this program provides several choices after each question, each choice associated with a different machine decision. The correct answer takes the learner to the next main item of the program. Each error possibility takes him somewhere else. The next item depends upon the programer's perception as to the type of difficulty it represents. In effect the programer interprets in advance the error possibilities and builds into the program different branches or side sequences to take care of these difficulties. For instance, if because of the nature of the learner's answer, it is assumed that he failed to grasp the question initially, he is told to reread the question. In this case the branching route takes him back to the original question. Another type of interpretation results when the learner has failed to make use of information presented earlier; in this case he is required to go back to an earlier question and its associated information to find what he needs to know. This routing is based upon the assumption that the learner either answered correctly by chance when he first saw the earlier item, or that he forgot what he learned when he first read it.

The so-called "quickening procedure"—telling the learner the consequence of his response before he completes it—is another type of programing; it does not necessarily alter the content of the program that is quickened. An example of quickening is the strange sound heard while dialing i.e., before all the numbers have been dialed; it is built into the telephone system to indicate that a nonexistent telephone number is being dialed. As soon as it is heard, the individual stops dialing so that the equipment is not not tied up as long as it would otherwise be. The "quickening procedure" requires a sophisticated machine. The programer can also use the dimensional characteristics of the correct responses to achieve a particular educational objective. For instance, if it is desirable to teach the student to respond more and more quickly while acquiring a particular skill, the machine—through the response unit and comparator—can modify the rate of presentation of the program. Obviously some limiting values based on the learner's capabilities have to be introduced.

Another programing procedure using the learner's correct response is dependent upon the existence of sequences of correct answers; consequently, the collator-recorder unit is involved. This is called forward branching (Coulson and Silberman, 1959b). In this case, the program is condensed on the basis of a series of correct responses. A few critical correct responses may be sufficient to indicate that the learner understands the concept and can therefore skip items others need to see. If the learner makes an error later on, he may be required to go through the steps which had been skipped earlier.

10. *Computer.*—The computer is a prime requirement for a versatile teaching machine system. It can perform all the functions described and illustrated in figure 2; it has been incorporated in a few very sophisticated teaching machines such as Pask's (1958c), IBM 650 (Rath, Anderson and Brainerd, 1959) and the University of Illinois' Illiac teaching machine. The computer requirement is typically implemented by less costly components; however, a high-speed electronic digital computer may turn out to be more efficient for doing

the job. The computer's function is to compose variant programs from a basic program as needed by each learner in the course of the teaching session itself. It has its own program telling it what to do in case of different types of errors; thus it can take into account the record of previous responses made by the learner and several response parameters at once in making its decisions.

In other words, the modern computer allows for a more complete adaptation of the teaching machine to the learner. It has been used in an interesting manner in the Pask teaching machine (1959c) where the "strategy of teaching" is based on a partly competitive, partly cooperative game. For example, the learner is asked a question; if he answers correctly, the machine, through the intervention of the computer, presents him with a more difficult question: a competitive game. If the learner answers the question incorrectly, the machine presents a more simple question: a cooperative game. The computer thus decides upon the intrinsic composition of the program according to pre-established criteria such as those just mentioned. Its strategy and the learner's responses are combined to determine the selection sequence from the available library information. The computer also can control the rate at which information is presented to the learner. For instance, in the Pask punchcard skill teaching machine (1958b, 1958c), the rate at which the punching task is presented to the learner is a function of its present performance. In other words, as the learner punches cards more rapidly, the machine increases the rate of presentation of the information to be punched, up to a criterion limit. If the learner improves his punching slowly or makes too many errors, the machine slows down the rate of presentation.

The preceding analysis has attempted to make explicit the requirements of complete teaching machine systems as the present state of the art appears to reveal them. As already mentioned, the implementation of many of these requirements can be extremely simplified by relying upon the learner to perform them or upon simple devices; however, for certain types of teaching this is an undesirable solution to the problem of implementation.

Adaptivity

Adaptivity in a teaching-machine system is the capacity of the machine and its associated program to adjust, in one way or more, to the specific needs of the individual learner; thus, it is probably the most critical feature of a teaching machine system. Each of the basic functions of the 10 requirements outlined is an explicit description of the way in which a teaching machine may be adaptive. Three varieties of teaching machine systems are emerging: (*a*) the minimally adaptive, (*b*) the partially adaptive, and (*c*) the adaptive. In describing these systems the words "machine" and "hardware" are used in the generic sense; they include paper and printed devices as well as wood and metal.

In the minimally adaptive system the programing is of the linear type. Ordinarily, after one exposure of the program the machine is reloaded and the same set of materials used again. The machine does not drop out items, nor does it adapt to the learner's rate of work. Moreover, a teacher is necessary to interpret the learner's responses and to decide about the knowledge of results that will be provided. In other words, a minimally adaptive system is unresponsive to individual differences among learners. While some functions of teaching are mechanized, many are still implemented by the teacher or not performed at all.

The minimally adaptive system might be described as a pseudoteaching machine or a teaching aid. It typically embodies some of the functions of a teaching machine but not enough of them. In general it is an open-loop system. If one uses as a criterion for the evaluation of a teaching machine system the 10 requirements previously listed, the deficiencies of the nonadaptive or minimally adaptive machine are indicated in table 1. It lacks a comparator unit, a feedback unit, a selector unit, a collator-recorder unit, and, of course, a computer.

TABLE 1.—*Summary of teaching machine functions in relation to classes of adaptivity*

Functions	Classes of teaching machines [1]		
	Nonadaptive	Partially adaptive	Adaptive
1	2	3	4
1. Presentation (display)	+	+	+
2. Response	+	+	+
3. Pacing:			
a. Machine	+	−	+
b. Learner	−	+	+
4. Comparator	−	±	+
5. Feedback	−	±	+
6. Collator-recorder	−	+	+
7. Selector:			
a. Go/no-go	−	+	+
b. Pattern	−	−	+
8. Library (storage):			
a. Basic only	+	+	+
b. Reserve for branching	−	−	+
9. Program:			
a. Noninterpretive	+	+	+
b. Interpretive	−	−	+
10. Computer	−	−	+

[1] The plus sign indicates that the function is represented; minus means it is not; the ± indicates that the function may or may not be included.

Moreover, the pacing of the program is done by the machine, not by the learner, and the programing is the linear, noninterpretive type.

The partially adaptive machine, as shown in table 1, implements nine requirements of a teaching machine system either by actual hardware, by the direct intervention of the learner, or by a combination of the two. It differs from the minimally adaptive machine by fulfilling the following requirements: comparator, feedback, collator-recorder, and selector (binary), with either an interpretative or a noninterpretive program; if the latter program is used it is coupled with the adjusted-learning method.

The adaptive teaching machine, as shown in table 1, implements all the functions of a teaching machine system. A key characteristic of an adaptive teaching machine is its ability to branch or otherwise alter the teaching program as a function of the learner's responses during learning. In other words, it can be said to develop, on the spot, a specific program for each learner within the limits of the library and its own programing strategy. The limits to which this type of system can be developed are not known at the present time, but computer technology promises to make this type of machine the primary one of the future.

CHAPTER III

Teaching Machines

SOME EARLY DEVICES

Certain innovations in education give perspective to current developments which themselves are in rapid transition. As early as 1866, for example, Halcyon Skinner developed and patented a spelling machine (Mellan, 1936) which was conceived as an aid to the teacher. About 1873 Jevons (1958) developed a logic machine, a device designed to generate solutions to logical problems represented symbolically.

Ordahl and Ordahl (1915) built a simple teaching machine to teach a serial skill to mentally retarded children; however, this machine apparently was designed primarily as a research instrument to increase the experimenter's efficiency. H. B. English (1942) invented a device used in 1918 to help train soldiers to squeeze a rifle trigger. It provided visual feedback through the use of a manometer with a visible liquid column that moved upward slowly if the trigger was squeezed.

Pressey (1926, 1927, 1932, 1958) beginning about 1915 made a deliberate effort at the Ohio State University to mechanize testing and teaching as much as possible. Pressey's early devices in this connection were designed mainly to supplement regular classroom instruction; they provided the student with rapid knowledge of results through the immediate scoring of his answers to specific questions.

Although many of the teaching devices now available are by comparison with these earlier conceptions more sophisticated in their engineering and more inclusive in the functions automated, some of them perform fewer functions than the earlier devices.

At the present time there are probably over 100 new devices under development and in use as teaching machines. This chapter will attempt to classify, list, and describe some of the available devices, many of which are still in prototype form. This attempt at classi-

TABLE 2.—*Minimally adaptive automation: Critical requirements and available machines, 1960*

Minimally adaptive machines and references	Critical requirements									
	Presentation (display)	Response	Pacing	Comparator	Feedback	Collator/Recorder	Selector	Library	Program	Computer
1	2	3	4	5	6	7	8	9	10	11
Film analyzer, classroom communicator. Twyford	Film	Selective; multiple choice.	Machine	Yes	No	No/Yes	No	Basic	Noninterpretive.	No.
Film communicator Carpenter, C.R.	Film	Selective; individual or group.	do	No	No	No/Yes	No	do	do	No.
Film viewer[1] (automatic loading, portable). Kopstein et al. (1959)	Film, (16-mm) and sound.	Selective	Learner	No	No	No/No	No	do	do	No.
Flashcard	Printed	Constructed	do	No	No	No/No	No	do	do	No.
Lear Mfg. Co	2- x 2-in. slides	Selective	Machine	No	No	No/No	No	do	do	No.
Memory Drum McGeoch & Irion	Printed	Constructed	do	No	No	No/No	No	do	do	No.
Omnideck used with processing equipment. Homme (1959)	Printed on IBM or Remington cards.	Constructed or selective; recognition.	Learner	Learner	Original level; visual.	Yes/No	No	do	do	No.
Subject-matter Trainer (SMT) Test Mode. Besnard et al. (1955)	Printed	Selective	Learner or machine.	No	No	No/Yes	No	do	do	No.

[1] Illustrated in reference article.

fication uses the notion of adaptability as a differentiating concept, on the assumption that for practical purposes it is indeed important to know first of all whether or not one is dealing with a minimally adaptive, a partially adaptive, or an adaptive machine. Moreover, to differentiate among the machines we have listed 10 requirements which a maximally adaptive teaching machine system should meet. These are considered in characterizing several available devices in terms of the functions they perform. (See tables 2, 3, and 4.)

MINIMALLY ADAPTIVE MACHINES

An example of a minimally adaptive teaching machine, as shown in table 2, is a deck of flashcards with stimulus or cue material on one side and associated response material on the other. The cards are presented, one at a time, to the learner, who responds to the stimulus material appearing on one side of the card and checks his response by looking at the other side. Typically, a predetermined time interval elapses between the showings of the two sides of a card. If the learner anticipates the answer correctly, he is provided with knowledge of results when the reverse side of the card is presented. Even if the learner responds with an incorrect answer, or fails to respond in the allotted time, he still sees the other side. The program, in this case the card sequence, is thus identical for all learners.

Another example of a minimally-adaptive machine is the memory drum, so often used in the psychology laboratory to study verbal learning (McGeoch and Irion, 1952). It is simply a mechanized flashcard system in which some, but not all, functions performed by the teacher with flashcards are built into the machine. There are two basic varieties. One uses a belt or loop of paper on which material is typed. The material is exposed by the movement of a belt rotated by a constant speed motor and is viewed through a slot on a panel facing the learner. A series of pins on a rotating drum positions the belt to expose a unit of material for a predetermined interval and moves the belt forward. The other variety of memory drum is a covered horizontal disc rotated by a motor, like a phonograph record, and controlled in its rotation so as to move a small angular distance at a time. Covering the disc is a solid upper plate in which there is a cutout that exposes one item of the preprogramed material at a time.

The teaching program can be the same with both types of memory drum. For example, if the anticipation method is used in programing, the learner first sees the stimulus term or cue by itself, and after a fixed interval, the machine shows it to him paired with the response term. The experimenter provides knowledge of results by saying "right" or "wrong." If the prompting procedure is used instead, the program first presents the cue to the learner and then the correct response. The learner is prompted to make the correct response once he sees it. Still another procedure is to alternate the prompting and anticipation (or test) procedures on successive trials.

The memory drum, when used in either way, is one component of a teaching system consisting of the machine, a program, a teacher, and a learner. The machine and experimenter together perform the functions of an adaptive teaching machine; both a machine and the presence of a teacher are still required during the learning process.

The subject-matter trainer (Besnard, Briggs, Mursch, and Walker, 1955) illustrated in figure 3 was developed and used by the U.S. Air Force in technical training. It permits five teaching modes and one testing mode of operation. In the testing mode, set in by the teacher through a controlling mechanism, the machine tests the performance of the learner after a training session. The machine when set for performing its teaching capabilities is really of the adaptive type; however, when used in the testing mode it is only minimally adaptive.

The Carpenter (1950) and Twyford (1954) mass-media mechanism (see table 2) is a minimally adaptive teaching machine used with a film presentation or with a lecture. Following a question asked by the teacher or projected from film, each member of the group responds, and each response is made known to the teacher. An individual multiple-choice response device is located at the student's desk, and the response of each student is recorded on a panel at the teacher's podium. Knowledge of results is fed back to the group either via the teacher himself or via a visual display containing counters. All responses to questions are recorded; this information is available for a number of uses, one of which is to alter the program of instruction.

The automatic loading, portable, 16-mm. film viewer (Kopstein, 1959) is a prototype device developed by the U.S. Air Force which permits the presentation of audiovisual material (table 2). The film can be moved either forward or backward or stopped to show one frame at a time. This device was primarily designed to teach motor skills such as assembly, disassembly, and repair of equipment. The Lear Manufacturing Co. has produced a prototype device similar in function but different in design in that it uses a magazine tape and a slide projector.

The information summarized in table 2 concerns some of the devices which are incomplete by themselves. Since they need a teacher or some auxiliary help to the learner for efficient instruction, they are classified as devices with minimally adaptive automation features. The first column includes the bibliographic reference concerning the device. Also included (col. 2) are the method of presentation (e.g., printed, film) and type of response required of the learner (col. 3). Entries in column 3 indicate whether a constructive or a selective response is required. The pacing source is indicated in column 4; it is either the machine or the learner. In column 5, two things are indicated: (*a*) Whether a comparator function is performed (it is not in testing) and (*b*) who performs it (e.g., teacher, learner, machine, or a combination of them). Column 6 indicates whether feedback is provided by the device (usually "No" for minimally adaptive automation devices) and at what symbolic level it is provided (same level as the question is coded as "original level"). Column 7 contains two entries relating to collating and recording: the first indicates whether the machine does the collating and the second whether it records. While the machine may record (sum) but not collate, the reverse is not found; none of the minimally adaptive machines provides a collator function. The selector function (col. 8) is not performed by the minimally adaptive machine; however, it is possible for the teacher to use the adjusted learning method (see Woodworth, 1938) to drop out items as the learner reaches a particular criterion. In column 9, the basic type of library is indicated. In other words, every learner sees the same total information. The type of program accommodated by the minimally adaptive machine is indicated in column 10 as noninterpretive (linear). As shown in column 11, none of the minimally adaptive machines has a computer.

PARTIALLY ADAPTIVE MACHINES

Several partially adaptive machines are described in table 3. A certain number of them not only present the stimulus material to the learner in printed form but also are in and of themselves printed devices. In table 3, for convenience, the paper-and-pencil devices are grouped separately from the hardware-type of machine. Most of these devices—hardware or printed—are built to measure recognition; they require a multiple-choice response. A few require the learner to compose his response either by constructing his answer through the manipulation of sliders (e.g., Skinner, 1954) by using keys, or by writing on a separate sheet of paper to be compared with the correct response that he later sees. Most of the hardware devices that do not require written composition, perform the comparator function for the learner. Typically, the hardware or printed devices which use written responses require that the learner perform the comparing himself, e.g., Porter's (1958a) machine; Skinner's (1954) disc machine; Magers (1959a). To do otherwise for handwriting would go beyond the present level of technology. (See Diemond, 1957, for a beginning in this direction.)

Almost without exception, in these devices the learner is given direct feedback by being allowed to see the correct response once he has given his answer. They differ from multiple-choice devices (e.g., Pressey, 1926, 1927) in that the learner sees the correct answer only after he has responded. With the multiple-choice device he sees the correct and wrong answers before he makes his response. Sometimes, additional and more immediate feedback is provided by colored lights (e.g., green for correct, red for incorrect answer) or by a buzzer sound (Besnard, Briggs and Walker, 1955; Briggs, 1958). The most common characteristic of these devices is that they are paced by the learner. Some of them also can be used to pace the learner, but this is a special mode of operation. Pressey's (1926, 1927, 1932) Drum Tutor and Skinner's Disc-machine (Edwards, 1956) perform the selection function based on the "adjusted learning method." With all the other devices, the teacher has to perform the selection function. Most of the devices perform the collator-recorder function. The majority of the devices use noninterpretive or linear programs and have only basic libraries. Exceptions are the projector programer (Davis, 1959), the pull-tab printed device (Glaser, Damrin, Gardner, 1954), the Trainer-Tester printed device (Cantor, Brown, 1956; Dowell, 1955), and Crowder's scrambled textbook (1958a, 1959) or tutor text.

The subject-matter trainer or S.M.T. (Besnard, Briggs, and Walker, 1955) is a low-capacity device in that it stores a maximum of 20 programed items and their answers. As already mentioned, the S.M.T. has 5 different teaching modes: the coaching mode, the single-error-permitted mode, the practice mode, the single-try mode, and the paced-practice mode.

In the coaching mode (also called quiz mode), the learner literally quizzes the machine by selecting a programed question. Once the learner has pressed a button, a green light goes on next to the correct answer. The learner is then required to press a button across from the correct answer in order to go on to another question.

In the single-error-permitted mode, the student is presented with a question and is allowed to make only one choice among alternative answers. If the answer is correct, the green light glows; if incorrect, a buzzer sounds or a red light goes on while the green light glows next to the correct response.

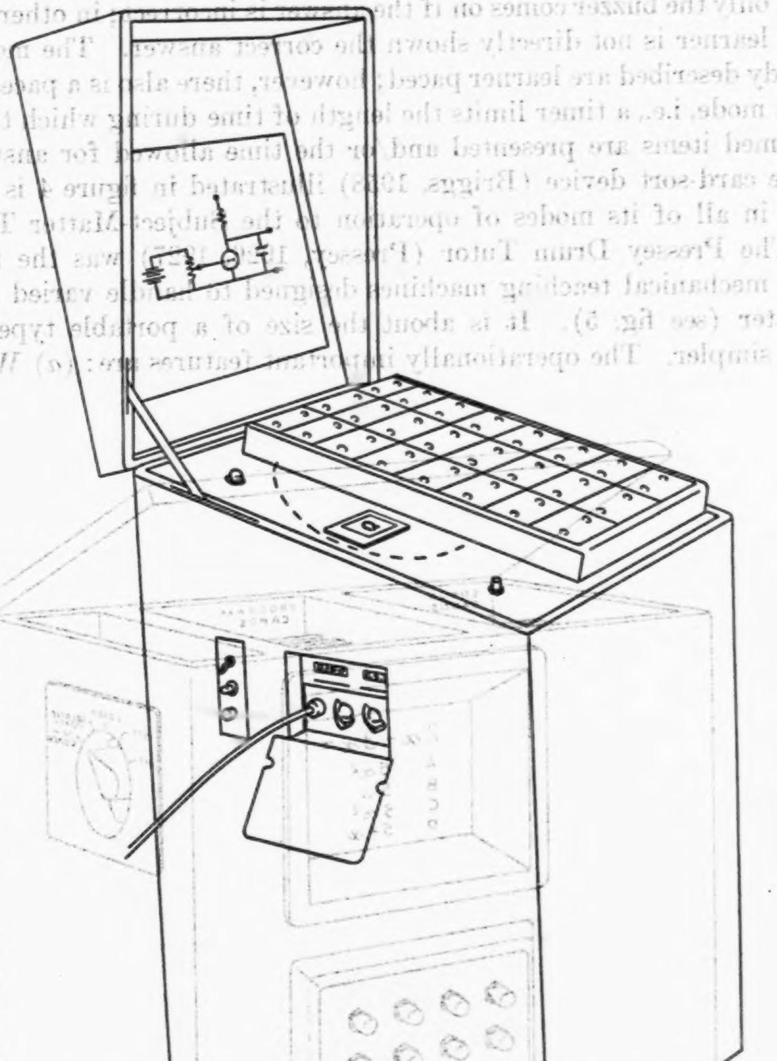


Figure 3. SUBJECT–MATTER TRAINER (SMT)

In the practice mode, the learner can make any number of errors. The green light glows when he finally selects the answer that is correct; the buzzer sounds after each incorrect answer.

In the single-try mode the student is allowed only one try to answer a question. The green light glows if the answer is correct, but only the buzzer comes on if the answer is incorrect; in other words, the learner is not directly shown the correct answer. The modes already described are learner paced; however, there also is a paced-practice mode, i.e., a timer limits the length of time during which the programed items are presented and/or the time allowed for answering. The card-sort device (Briggs, 1958) illustrated in figure 4 is identical in all of its modes of operation to the Subject-Matter Trainer.

The Pressey Drum Tutor (Pressey, 1926, 1927) was the first of the mechanical teaching machines designed to handle varied subject matter (see fig. 5). It is about the size of a portable typewriter, but simpler. The operationally important features are: (*a*) Window

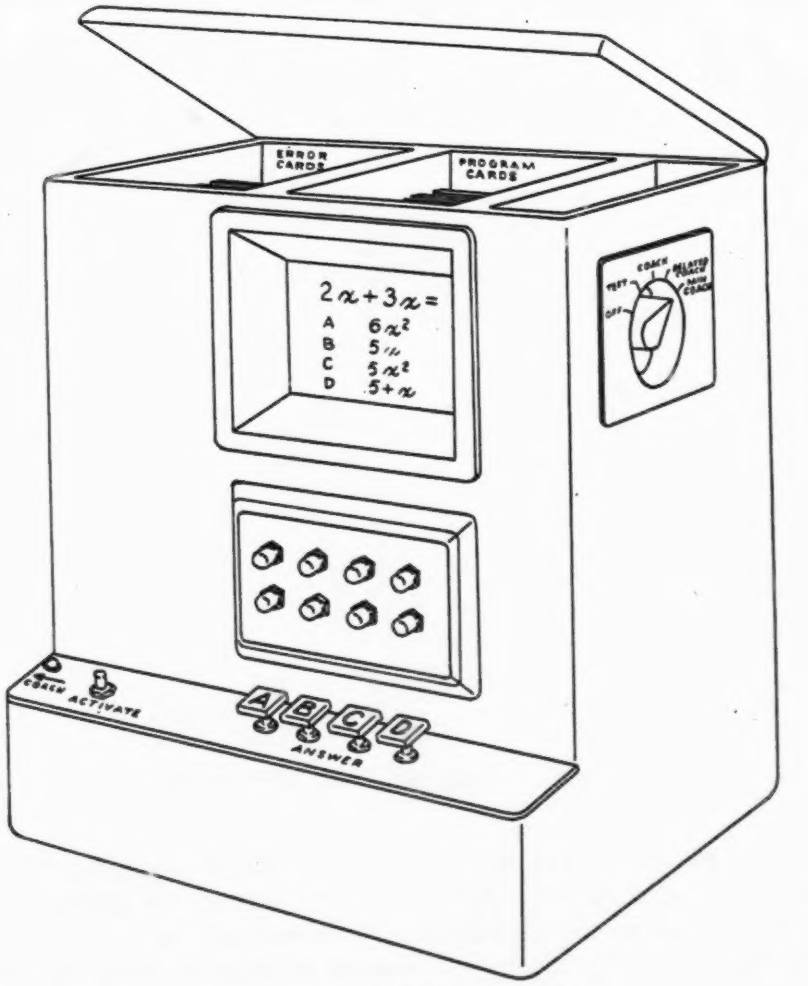

ERROR CARDS
PROGRAM CARDS
OFF
TEST
COACH
RELATED COACH
MAIN COACH
2x+3x=
A 6x²
B 5x
C 5x²
D 5+x
COACH
ACTIVATE
A
B
C
D
ANSWER

Figure 4. CARD-SORT DEVICE

(display unit) revealing a question with multiple choices (usually four); (*b*) four keys (response unit); and (*c*) the typed sequences of questions (program). It has both a test mode (no feedback) and a teaching mode in which feedback is provided by the appearance of a new question when the correct response is made, or by no change in the window when a wrong response key is pressed.

The correction procedure is built in; the learner has to make the correct response before he can see the next question. A counter records all trys (recorder unit). Four retractable fins are mounted on the drum—one per alternative—and each question is represented on the drum by a separate row of four fins. The machine is programed for a particular subject-matter or item sequence by pushing in the fin corresponding to the correct key response. A separate attachment provides candy, or other reward, as reinforcement.

Later the device was modified (Pressey, 1927) so that it presented the same question until the learner answered correctly on his first try twice in succession (or on three or four successive tries). When this criterion was reached, the item was skipped the next time. After every item is mastered, in terms of the criterion used, the machine automatically stops and releases a small coupon to indicate that that lesson has been mastered. This device has a drum capacity of 30 items (two typewritten lines each). The information concerning the correctness or incorrectness of the answers is conveyed by the machine. In the modern version of the device (Pressey, 1950a) illustrated in figure 6 the questions and their multiple alternative answers are presented on a printed page used side by side with the machine. A drum is located inside the machine which contains, on the outside, four response keys.

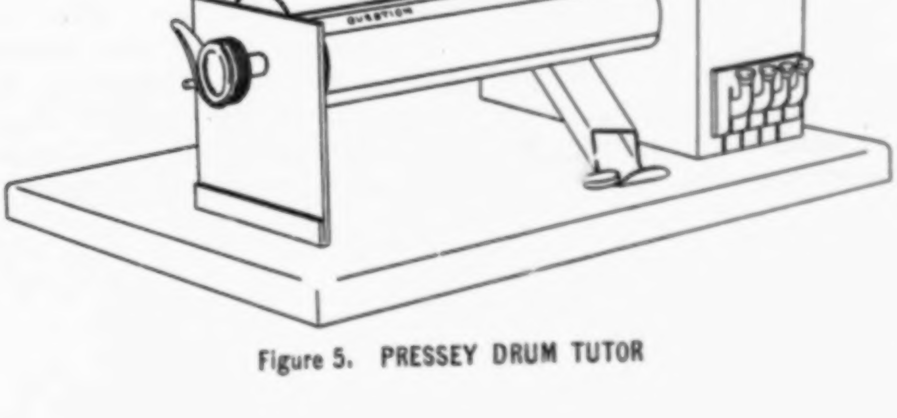


Figure 5. PRESSEY DRUM TUTOR

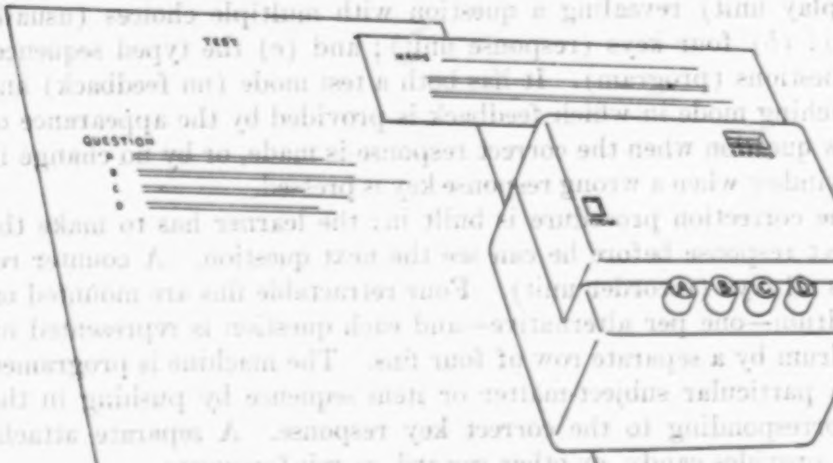


Figure 6. PRESSY MULTIPLE-CHOICE MACHINE

Several different patterns of answers are each coded on a different drum; this allows the teacher to program a variety of sequences of correct choices, thus avoiding sequential hints to the learner. As in the earlier version, the learner must select the correct answer before he goes on. A bell sounds every time the learner makes an error; a counter totals up the number of errors (see fig. 6).

Skinner has been instrumental in the development of a teaching machine (Skinner, 1954) patterned after Pressey's device and another one based upon the disc memory drum. Each is about the size of a portable typewriter or record player. For the machine illustrated in figure 7 the program is printed on a sheet of paper in sectors of a circular area. Each pie-shaped sector of the circular section is allotted to a question, or an answer, as illustrated in figure 8.

The learner's responses, usually single words, are written on a paper tape, which is separate from the program disc. After the learner has written his answer he actuates a handle and thereby moves his response under glass so that it cannot be changed. As he proceeds, the correct answer is revealed by the machine. Both the problem (or question) and the answer appear in windows on the top surface of the box indicated by Q and A, respectively, in figure 7.

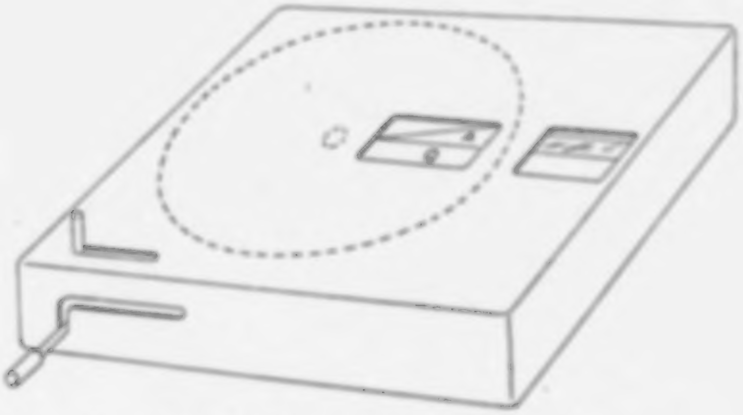


Figure 7. SKINNER DISK MACHINE

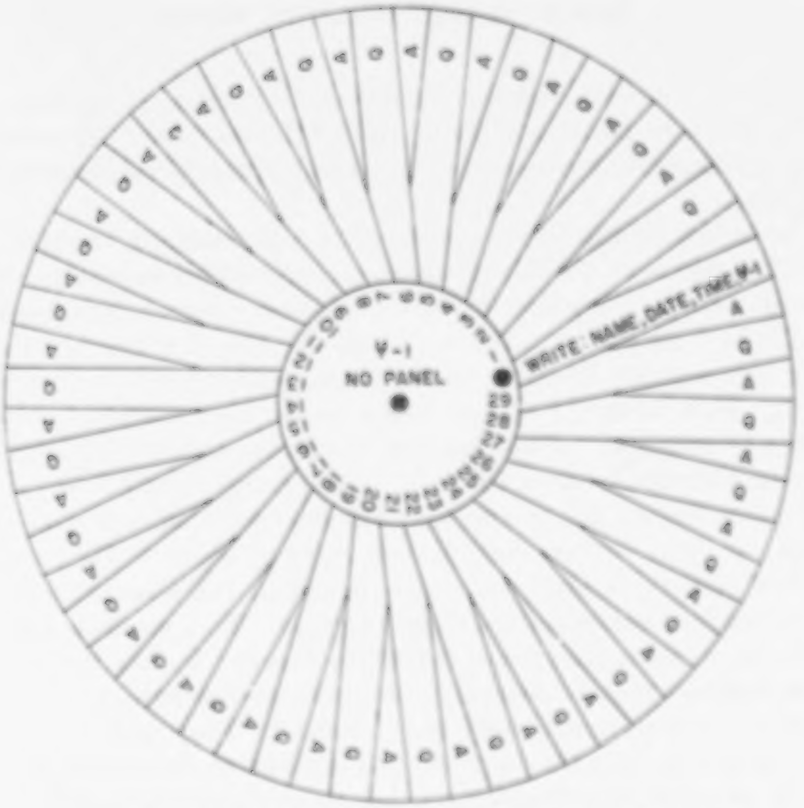

V-1
NO PANEL
WRITE: NAME, DATE, TIME V-1
A
Q

Figure 8. PROGRAM DISK FOR THE SKINNER MACHINE

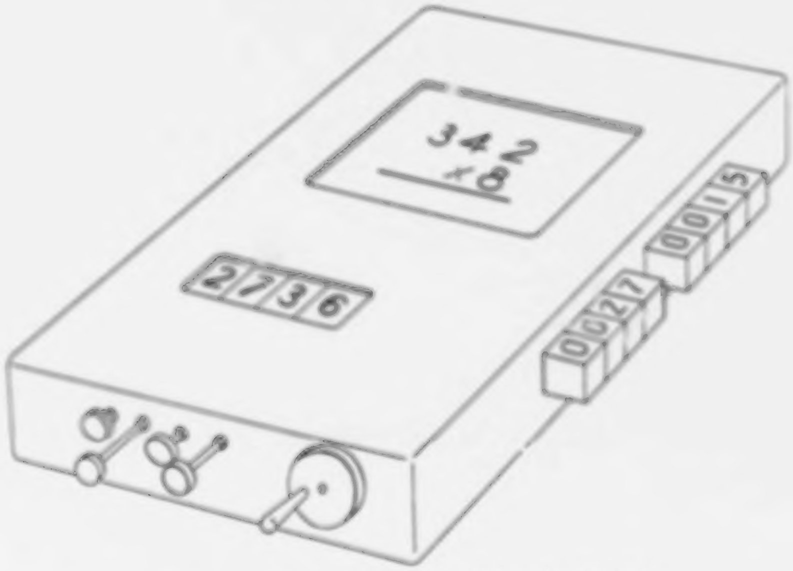


Figure 9. SKINNER ARITHMETIC MACHINE

The learner decides whether his answer is correct or incorrect. If it is correct, he moves a lever on top of the machine; this automatically perforates the paper so that the same programed item does not reappear.

The earlier Skinner device is the arithmetic teaching machine illustrated in figure 9. In this the learner composes his answer to a problem by manipulating four answer keys, each capable of representing the digits 0 through 9. When the learner feels his answer is right, after any number of corrections he may care to make, he turns a crank. This locks the sliders into place, so that the answer can no longer be changed. Knowledge of results is provided by seeing the answers through holes in the tape. Answer keys just below the window cause the answer to appear. The device can also provide a bell sound or give other conditioned reinforcement. The machine "knows" the right answer to each problem; the learner cannot go ahead until he composes the right response. This machine also provides for an automatic recording of the errors. It, like the disc machine, does not require outside power; both are mechanically operated by the learner and completely self-contained. They differ from Pressey's device in that they prevent the accidental conditioning of the wrong response, since the learner has to construct the answer rather than recognize it from among a set of mostly wrong alternatives.

The "polymath" (described by Lumsdaine, 1959b) was designed by Rothkopf. The model illustrated in figure 10 could be used to teach

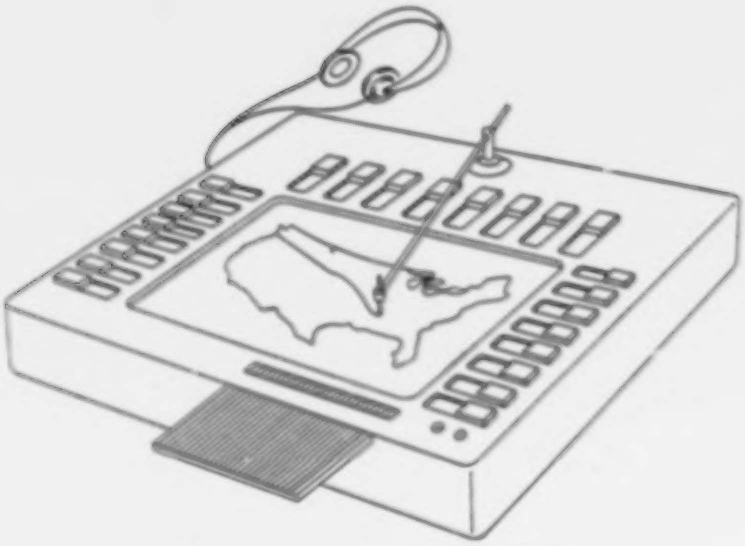


Figure 10. ROTHKOPF POLYMATH

geography, for example, or geometry, where a continuous response is being taught. It is not limited to this, however, since the instructor's panel (not shown) also controls the small translucent rectangles around the edge which permit the teaching of material involving discrete, multiple responses. Any set or all of these small panels can be used, as required. The device is equipped with a "state switch" that permits the instructor to stay one state ahead of the learner in setting up the machine for automatic feedback. The learner can compose an answer that requires 29 "bits" (binary digits; e.g., on/off) including letters and spaces between them, for example. This is a versatile machine; it is really a flexible "response gate" capable of comprehending several "response languages." To date only one prototype has been built, and it has not been used in research.

House, Zeaman, Orlando, and Fisher (1957) designed a machine for teaching arithmetic to mentally retarded children. This device is similar to the Skinner arithmetic machine, already described, but is somewhat more ruggedly constructed. The learner positions his answer with sliders, turns a crank, and if the answer is wrong the crank will only turn ⅛th of a revolution. If the answer is correct, however, the crank turns one full revolution, and the learner can proceed to the next problem. The machine is self-contained and is equipped with a slip clutch to prevent overenergetic operation.

Some prototype devices have also been designed for teaching preschool children or illiterates sight vocabulary, discrimination, or simple associative learning. One of the more recent ones, the DIDAK 101 (Rheem, 1959), is illustrated in figure 11. The machine has three answer or response windows located below the display or cue window. When the correct association is made by touching the appropriate answer window, the machine automatically presents the next problem.

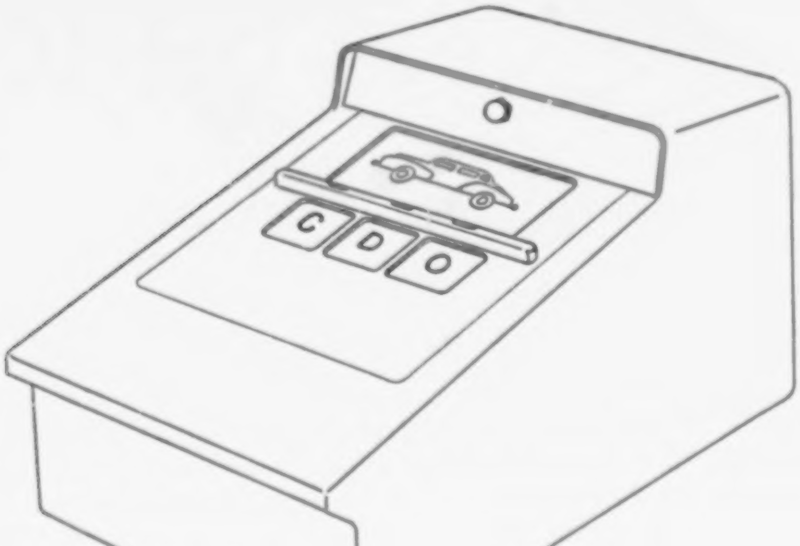


Figure 11. RHEEM DIDAK 101

A device for teaching sight vocabulary has been developed at the University of Illinois, under a U.S. Office of Education, Cooperative Research Program grant, for use with young mentally retarded children (Stolurow and Porter, 1960); it is illustrated in figure 12. The machine holds five programed cards on each of two parallel drums—a cue drum and a response-term drum. The drums are rotated by circuit-control discs which provide the programed sequence desired by the teacher. The teaching method can be changed from a prompting to a confirmation procedure, for example, by simply positioning a switch. The machine automatically returns the learner to the cue term if he is wrong; if he is right, it takes him to the next item. A wide range of exposure times also is possible by means of a simple adjustment of switches. The learner makes his response by pushing one of two switches alongside the display window, on the side next to the

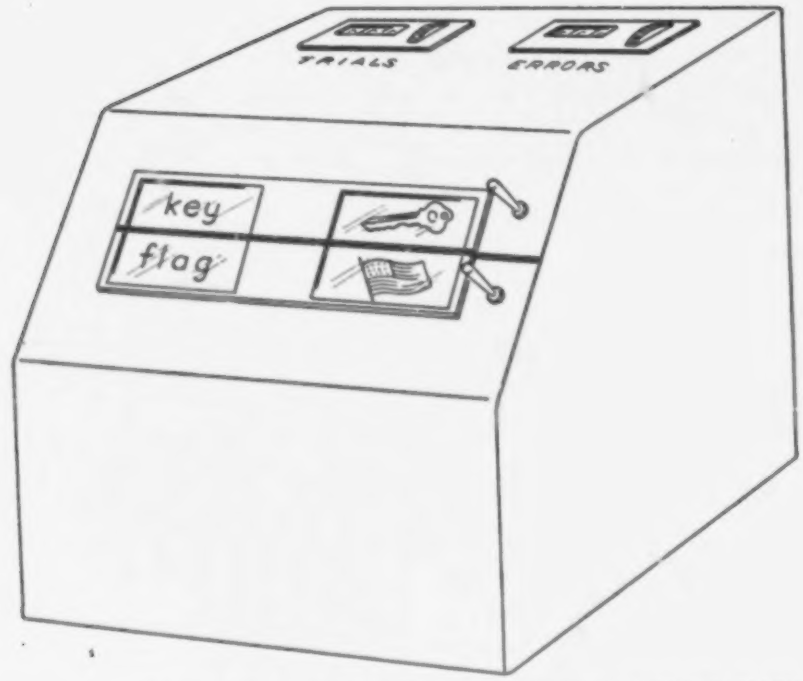


Figure 12. STOLUROW-PORTER SIGHT VOCABULARY MACHINE, MARK 1

response term. The teacher, or experimenter, changes the content of the program by placing a new set of cards on the drums.

The Autotutor is a partially adaptive machine built by Western Design (1959); it is illustrated in figure 13. Basically, Autotutor is an automatic, random-access, recording, microfilm, motion picture projector. The student finds the first unit of subject-matter information on image 1 of the microfilm, along with a multiple-choice question based on that unit of information. He then selects an answer to the multiple-choice question, enters into a keyboard the frame number (address) accompanying the answer he selects—a frame number is always located beside each alternative answer—and presses the "view" button. The device then automatically locates and projects the image that is at the address that was the student's choice. If the correct answer to the multiple-choice question was chosen, the image selected will not only contain knowledge of results—e.g., "you are right"—but also will contain the next unit of information, and the next question. If the incorrect one of the alternatives is chosen, the corresponding image will tell the learner of his error, provide information designed to correct the particular error, and direct him to return to the image at which he made his mistake and try again.

Built into the machine is a recorder which prints every image number chosen and the time elapsed since the previous choice. The keyboard and recorder are components of an electrically operated adding machine. Moreover, with this device motion picture material can be freely intermixed with still material. A motion sequence is

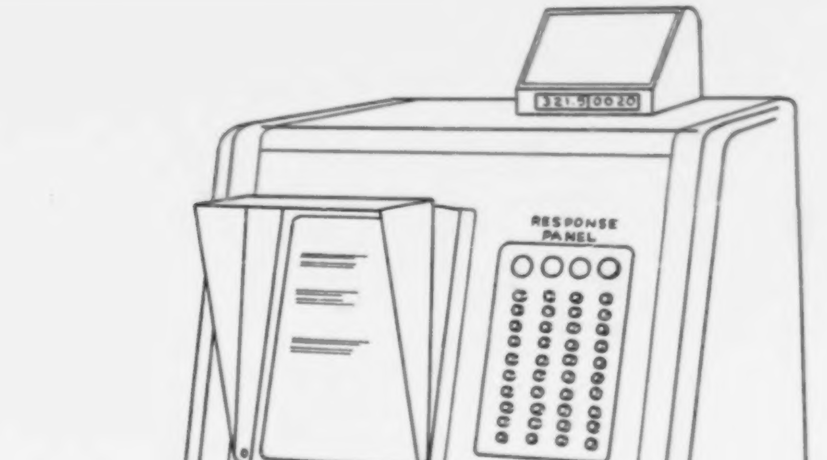


Figure 13. WESTERN DESIGN AUTO-TUTOR

simply displayed for the learner's viewing by punching into the keyboard or response unit the last frame number of the motion sequence that is desired (the next address) and then by pressing the "motion" button.

The Autotutor is a machine system for presenting, controlling, and recording a microfilm version of a printed program called the "scrambled book" described under the heading "printed devices."

Printed devices

Partially adaptive teaching machines (PAT machines) of the printed type are simpler than the devices described so far. They have been listed in table 3 with the other partially adaptive devices.

Pressey (1950b) has been instrumental in developing a punchboard device containing: (*a*) a solid piece of paper and (*b*) a precoded sequence of holes indicating the correct answers. The student uses the device along with a set of questions and accompanying multiple-choice answers. He reads a question, decides upon the alternative, and indicates his choice by pushing a pencil or stylus into the appropriate space on the grid. If the answer is correct, the pencil or stylus perforates the paper; if the answer is incorrect, the paper cannot be punched, since no answer hole is directly beneath. Consequently, the learner receives immediate knowledge of results. The student is instructed to punch the correct answer before proceeding to another question. The multiple choices are written on the accompanying text so as to conform to the number (usually four) and the positions of the correct alternatives built into the punchboard; a large variety of boards containing different sequences of correct responses can be used.

A punchboard device also was described by Peterson (1930). He called it the Self-Instructor and Tester. It had two different forms, mechanical and chemical, both used with lists of questions, problems, or exercises of the multiple-choice type.

The mechanical form had an opaque envelope with rows and columns of small circles printed on the visible surface, each row corresponding to a multiple-choice set and numbered to correspond with the printed items. The choices were lettered. There was a hard interior "selector" sheet inserted in the evelope, and directly beneath the correct circle there was a perforation. The student stuck a pin in the circle he thought was correct and received immediate knowledge of results.

The chemical form of the Self-Instructor and Tester had the same exterior surface, but here the correct circles were treated with one chemical and the incorrect ones with another chemical, both giving the same appearance. However, when brought into contact with a third

TABLE 3.—*Partially adaptive automation: Critical requirements and available machines, 1960*

A. Hardware type of machine

Partially adaptive machines and references	Critical requirements									
	Presentation (Display)	Response	Pacing	Comparator	Feedback	Collator/Recorder	Selector	Library	Program	Computer
1	2	3	4	5	6	7	8	9	10	11
Arithmachine. House et al.*	Visual	Constructed: sliders	Learner	Machine	Original level, visual and kinesthetic.	Yes/Yes	No	Basic	Noninterpretive.	No.
Auditutor. Blyth (1960a).	Tape	Constructed	do	Learner	Original level	No/No	No	do	do	No.
Autoscore. Astra-Zenith Corp.	Printed on plastic sheet.	Selective: recognition, electric stylus.	do	Machine	Original level; correction procedure visual.	No/Yes	No	do	do	No.
Automatic rater. Angell and Troyer; Keislar (1959a).	Film-group	Selective: 1 of 5 buttons.	do	Learner	Original level	No/No	No	do	do	No.
Card-sort device. Briggs (1958)**.	Printed	Selective: 4 choices	do	Machine	Original level, visual.	No/Yes-	Yes	do	do	No.
Didak 101 (discrimination learning, preschool children). Rheem Mfg. Co.	do	Selective; recognition	do	do	Original level, correction procedure.	Yes/Yes	No	do	do	No.
Dyna-Slide Program Scanner. Dyna-Slide Co.	do	Constructed	do	Learner or machine.	do	No/No	No	do	do	No.
Foringer machine. Foringer (1959).	Printed	Constructed-type	Learner	Learner	Original level, visual.	Yes/Yes	No	Basic	Noninterpretive.	No.
Machine Drum Tutor (multiple choice). Pressey (1926, 1927, 1932)**	do	Selective; recognition	do	Machine	do	Yes/Yes	Yes	do	do	No.
Mager machine. Mager (1959c).	do	Constructed; drawing.	do	Learner	Original level	Yes/Yes	No	do	do	No.
Multiple-choice machine. General Atronics.	do	Selective; recognition (4 keys).	do	Machine	Original level, visual.	No/Yes-	No	do	do	No.
Optim[illegible]equence Trainer. Bryan and Schuster.	do	Constructed (recall) coded as 1-1,000.	Learner and machine.	do	Original level; visual, lights.	Yes/Yes	No	do	do	No.
Osler Foringer machine. Osler.	Film-group (35-mm.).	Selective; 2 choice stimulus-tape.	Learner	do	Original level plus token.	Yes/Yes	No	do	do	No.

Porter's machine Porter, D. (1958c).*	Printed	Constructed	Learner	Learner	Original level	Yes/Yes	No	do	do	No.
Projector Programer Davis Scientific Instruments.	Slides (35-mm.).	Selective	Learner or machine.	do	Original level	No/No	No	Basic or extensive.	Interpretive.	No.
Rothkopf's Polymath Lumsdaine (1958)**	Printed	Constructed, drawing.	Learner	Machine	do		No	Basic	Noninterpretive.	No.
Skinner machine:										
Arithmetic teaching Meyer, S. (1959)**	Visual	Constructed, with sliders.	do	do	Original level, correction procedure, visual.	No/Yes	No	do	do	No.
Multipurpose disc type. Day**.	Printed	Constructed	do	Learner	do	Yes/Yes	Yes	do	do	No.
Prereading problems Edwards; Skinner (1958b).	do	Selective; recognition, 5 keys.	do	Machine	Original level, visual.	Yes/Yes	Yes	do	do	No.
Subject-Matter Trainer Besnard, Briggs, and Walker (1955)**.										
Coaching mode	do	Mediating	do		Original level and light.	No/Yes	Yes	do	do	No.
Paced practice mode	do	Selective; multiple choice.	do	do	Original level, light and sound.	No/Yes	Yes	do	do	No.
Practice mode	do	do	do	do	do	No/Yes	Yes	do	do	No.
Single-error mode	do	do	do	do	do	No/Yes	Yes	do	do	No.
Single-try mode	do	do	do	do	do	No/Yes	Yes	do	do	No.
Teacher Sight Vocabulary C. Porter and Stolurow (1960).*	do	Selective	Learner and machine.	do	Original level, visual.	Yes/Yes	Yes	do	do	No.
Visitutor Blyth (1960a).	Filmstrip (35-mm.).	Constructed	Learner	Learner	Original level	No/No	No	do	do	No.
Western Design Autotutor. Western Design**.	Film (still/motion).	Selective; multiple choice (0-9,999).	do	do	Original level, visual.	Yes/Yes	No	Extensive	Interpretive.	No.
Word Recognition (deaf children) Falconer (1959).	Visual	Selective; recognition, multiple choice.	do	Machine	do	No/Yes	No	Basic	Noninterpretive.	No.

* Illustration in reference article.
** Illustration in this monograph.

TABLE 3.—*Partially adaptive automation: Critical requirements and available machines, 1960*—Continued

B. Printed devices

Partially adaptive machines and references	Critical requirements									
	Presentation (Display)	Response	Pacing	Comparator	Feedback	Collator/ Recorder	Selector	Library	Program	Computer
1	2	3	4	5	6	7	8	9	10	11
Cardboard mask Ferster and Sapon.	Printed	Constructed	do	Learner-machine	Independent of learner; visual.	Yes/Yes	No	do	do	No.
Chemo-card Peterson; Pressey (1950).	do	Selective: stylus with ink.	do	Machine	Original level; correction procedure, visual.	Yes/Yes	No	do	do	No.
Cut-back page Valentine.	do	Selective: information answer sheet.	do	Learner-device.	Original level, visual.	Yes/Yes	No	do	do	No.
Envelope and cardboard Peterson (1930).	do	Selective: punch holes.	do	Machine	Original level, visual, kinesthetic.	Yes/Yes	No	do	do	No.
Gilbert's device Gilbert, T. F. (1958a).	do	Constructed	do	Learner	Original level	Yes/Yes	No	do	do	No.
Pulltab; Tear-a-tab Bryan and Rigney (1956); Cornell et al.; Damrin and Saupe (1954); Cross and Galer; Glaser et al. (1954).	do	Selective: pull tab; or constructive, by component.	do	Learner	Original level, visual.	Yes/Yes	No	Extensive.	Interpretive.	No.
Punchboard Angell and Troyer; Pressey (1950b).	Printed	Selective; recognition	do	Device	Original level, visual; red dot if correct.	Yes/Yes	No	Basic	Noninterpretive.	No.
	do	do	do	do	Original level visual.	Yes/Yes	No	do	do	No.
Punchboard Tutor Cantor and Brown.	do	Selective; recognition (4 choices)	do	Learner/device.	Original level visual; tactual.	Yes/Yes	No	do	do	No.
Scrambled Textbook; Tutor Text. Crowder, N. A. (1958a and 1959).	do	Selective; any number	do	Learner/text.	Original level visual.	No/No	No	Extensive.	Interpretive.	No.
Stolurow and Walker device, Stolurow (1960).	do	Constructed answer sheet	do	Learner/device.	do	Yes/Yes	No	Basic	Noninterpretive.	No.
Trainer-tester Cantor and Brown; Dowell.	do	Printed by composition; selective (erase silver overlay).	do	Learner/machine.		Yes/Yes	No	Basic/extensive.	Interpretive.	No.

chemical the two treated portions responded differently: each turned a different color. This was not as convenient a form as the mechancial model; each page had to be prepared especially and required more time to get ready than a punchboard.

An extremely simple device has been used by Ferster and Sapon (1958) and Blyth (1960b); the program (information plus questions) has been typed to the left-hand side of a mimeographed text, the answer being located in a column to the right of the pages. The learner uses a cardboard cutout which reveals the program step but covers the answer. When the learner selects an answer, he moves the cutout and thus is able to compare his answer with the programed answer.

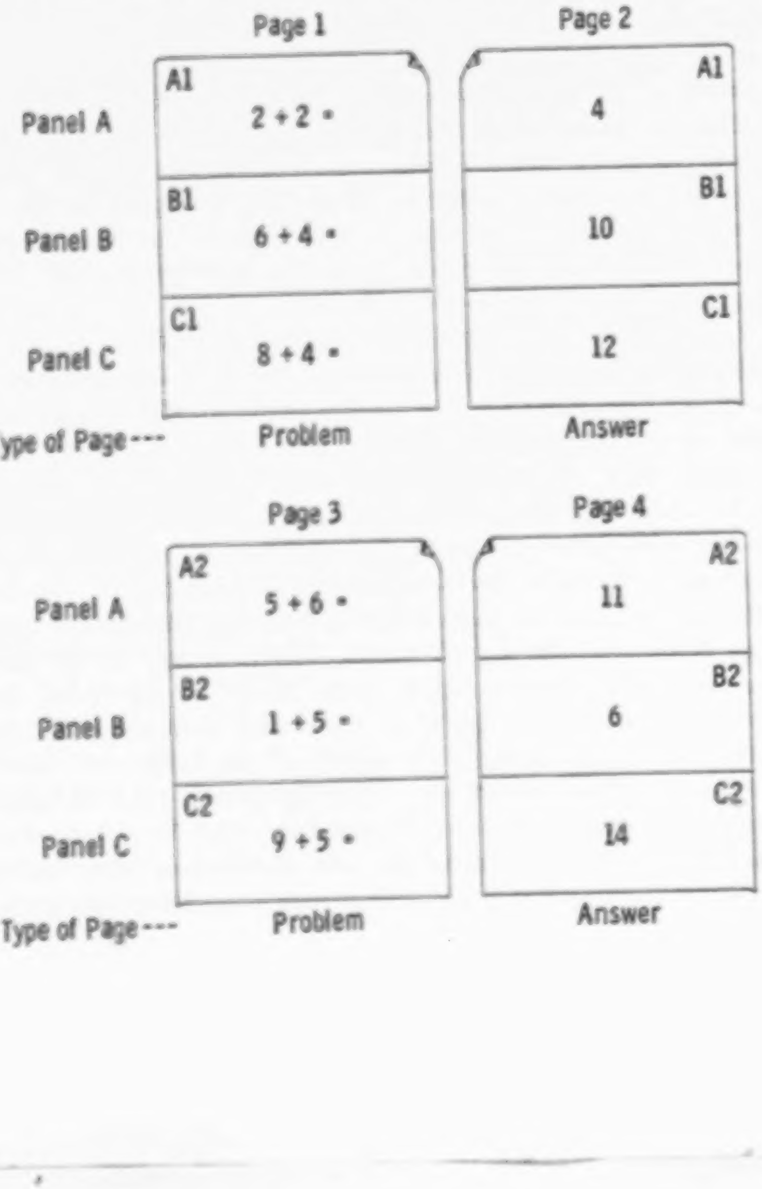
Four types of printed devices are: the programed textbook, the scrambled textbook, the cutback-page booklet and the tab-type page. Each of these devices conforms to a particular format, but each can be written according to a variety of programing rules.

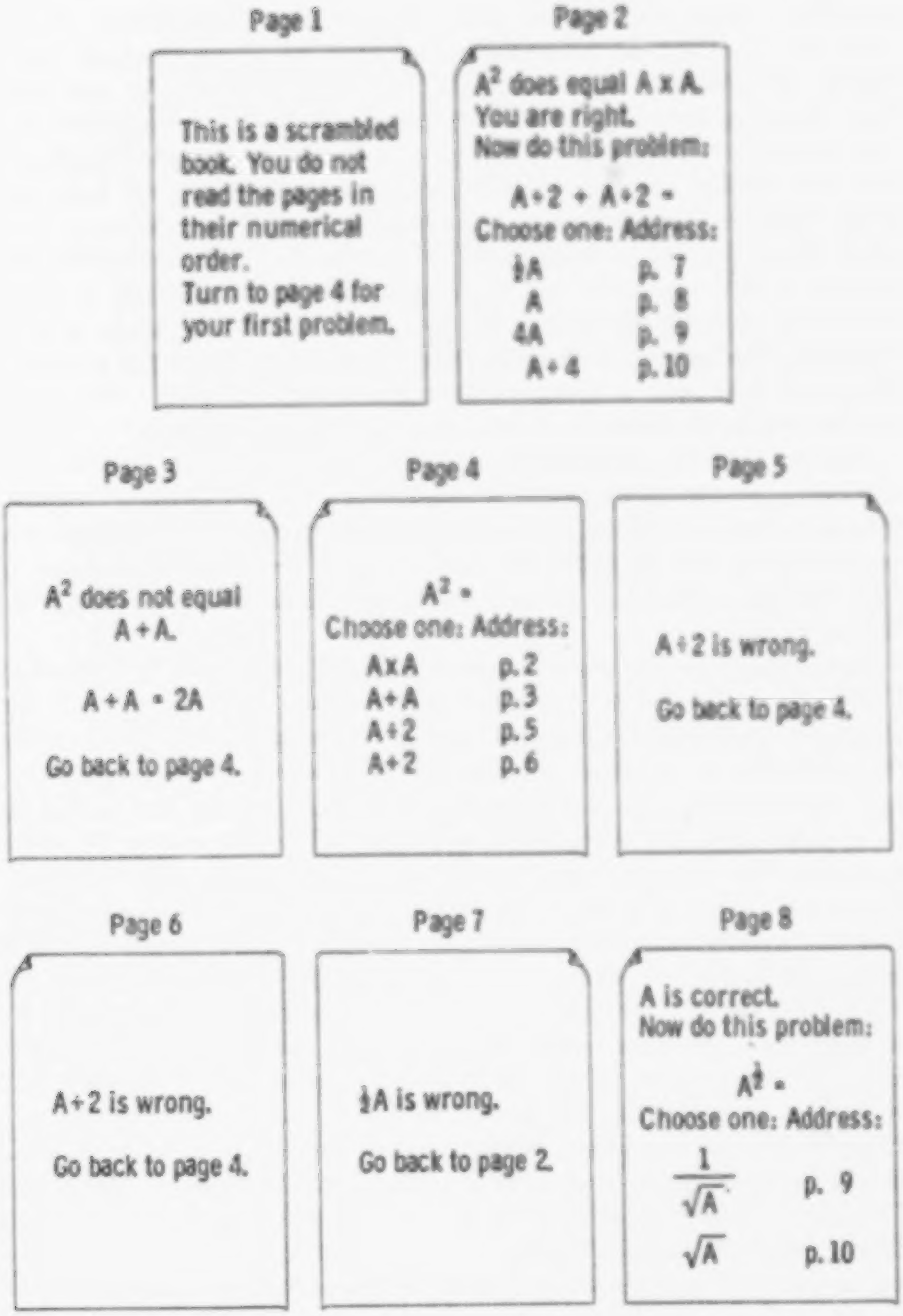
The programed textbook (Stolurow and Bergum, 1958; Homme and Glaser, 1959a), as illustrated in figure 14, is composed of two types of pages: the information-question page and the immediately following answer page. Typically, the information page contains: (*a*) Some of the data, information, concepts, etc. to be taught; (*b*) a problem or question, usually in the form of a sentence, with one or more blanks or deleted items; and (*c*) space for the learner to record his responses. After he does this, he turns to the answer page to read the correct response; as soon as he has compared it with what he wrote, he proceeds to the next information-question page, and so on throughout the book.

In this format knowledge of results is relatively quick, since the answer page immediately follows the information-question page. In order to limit the knowledge of results provided, the learner does one problem at a time; the questions, or problems, are printed on alternate pages with answer pages sandwiched in between. To save space, the information-question pages and their corresponding answer pages are subdivided into panels, as illustrated in figure 14. Thus, the learner starts with the uppermost panel on page 1 of the book, goes to the top panel on page 2 for the answer; then to the top panel on page 3 for a second question, etc. When he gets to the last page of the book, going from page to page using the top panel, he then goes back to page 1 and reads the panel that is next to the top. He proceeds as before through all pages of the book and returns to page 1 for the third panel, etc. The top panels may be lettered A throughout the whole book so the numbers read A–1, A–2, etc. The middle panels may be lettered B, and the bottom ones lettered C. Typically, this format is used with a non-interpretive program. In other words, all potential learners go over the same material regardless of the correctness or the incorrectness of their individual responses. Their responses do not determine what they see next. New information or new "steps" in the program appear in the identical sequence for all learners. It would be possible to take into account individual differences with this format, but it might be difficult.

The scrambled textbook developed by Crowder (1959) differs from the programed textbook both in format and in its underlying programing rules. With a typical scrambled textbook, the learner starts with the first page but is soon covering pages in a sequence that jumps back and forth; thus the name, scrambled textbook. The page numbers are not scrambled but rather the sequence in which the learner reads them. The sequence he follows depends upon his selection of the alternatives given.

Figure 14. SUCCESSIVE PAGES IN AN ARITHMETIC PROGRAMED TEXTBOOK


Page 1
Page 2
Panel A
A1
2 + 2 =
4
A1
Panel B
B1
6 + 4 =
10
B1
Panel C
C1
8 + 4 =
12
C1
Type of Page ---
Problem
Answer
Page 3
Page 4
Panel A
A2
5 + 6 =
11
A2
Panel B
B2
1 + 5 =
6
B2
Panel C
C2
9 + 5 =
14
C2
Type of Page ---
Problem
Answer



Page 1

This is a scrambled book. You do not read the pages in their numerical order.
Turn to page 4 for your first problem.

Page 2

A^2 does equal A x A.
You are right.
Now do this problem:

$A \div 2 + A \div 2 =$

Choose one:	Address:
$\frac{1}{2}A$	p. 7
A	p. 8
4A	p. 9
$A \div 4$	p. 10

Page 3

A^2 does not equal A + A.

$A + A = 2A$

Go back to page 4.

Page 4

$A^2 =$

Choose one:	Address:
AxA	p. 2
A+A	p. 3
$A \div 2$	p. 5
A+2	p. 6

Page 5

$A \div 2$ is wrong.

Go back to page 4.

Page 6

A+2 is wrong.

Go back to page 4.

Page 7

$\frac{1}{2}A$ is wrong.

Go back to page 2.

Page 8

A is correct.
Now do this problem:

$A^{\frac{1}{2}} =$

Choose one:	Address:
$\frac{1}{\sqrt{A}}$	p. 9
$\sqrt{A}$	p. 10

Figure 15. CROWDER SCRAMBLED TEXTBOOK

On a page there is: (*a*) Information pertaining to the subject matter; and (*b*) a question to which several alternative answers are provided. Next to each answer is a number. The learner is instructed to choose an alternative and then to go to the page indicated (an address). If he selects the correct answer, he will find the following information: (*a*) A statement that he is correct; (*b*) the reason for the correctness; (*c*) new subject-matter information; and (*d*) finally another question with alternative answers and new page numbers (or addresses). As before, the learner selects an answer, then verifies it immediately. If the choice is incorrect, the learner is told that it is and is given additional explanation to help him make a better decision. In the most common variation of this approach the learner is then directed to the page where the question appeared first and is required to make another choice. This procedure continues until the correct answer choice is made.

Figure 15 is an illustration of a scrambled textbook. Space did not allow for an explanation to be inserted on the incorrect pages; however, this is typically done. Thus the person who selected the second choice, for example A+A on page 4 in figure 15, might be told: "A+A is the same as 2A. Go back and read the problem with this in mind."

In its programing, the scrambled textbook developed by Crowder (1959) is interpretive; it presumably adjusts to the needs of the learner as anticipated by the programer. A problem that arises with the scrambled textbook in this connection appears to have gone unrecognized, however. It is that the time interval between the choice of an answer and the associated feedback will vary not only from learner to learner but also from problem to problem. For example, in the sample set of pages in figure 15, it is apparent that large separations in pages may occur, and these separations are correlated with delays in feedback. From results of laboratory studies of delay in feedback (either as reinforcement or as knowledge of results), it is clear that feedback should be immediate for maximally efficient learning to take place; thus the location of each answer page should be such as to minimize the amount of page turning. The degree of scrambling is an important determinant of the feedback interval, and should be considered with respect to the need for efficient learning.

All printed devices such as the programed textbook and the scrambled textbook are prone to a defect not present in the hardware teaching devices. They allow the learner to "cheat"; it is indeed possible for him to look ahead before he responds. Apparently, however, this has not been a problem to date (Homme and Glaser, 1959a); furthermore, from the point of view of learning, looking ahead may be a way of changing a confirmation procedure to a prompting procedure (see Cook and Kendler, 1956). Methodologically, however, it is a problem of experimental control and is an important limiting factor in the interpretation of research. If the learner can skip ahead before responding to the program item, control over the conditions of practice is lost. If each learner varies in the extent or frequency with which he looks ahead, the teacher (or experimenter) is not obtaining data under the same conditions for all learners. This problem is minimized in the scrambled textbook, for in it the learner does not know where to go next until he commits himself to one of the available alternative answers.

A way of implementing both the programed and the scrambled textbook to achieve convenience for the learner as well as economy in printing is the use of the cutback booklet format (Hobbs, 1947) illustrated in figure 16.

The "cutback" booklet is composed of assemblies of pages, each narrower than the preceding one. The size of the cutback is made to suit the need for text space, on the right, and writing space on the answer sheet, at the left. For example, there may be five different sizes of pages, one following the other, the largest one on top. This assembly is then repeated throughout the booklet as needed to cover the material. In other words, in the example given, the assemblies of five different widths are repeated as many times as required to cover what is being taught.

The cutback booklet has been used mainly in teaching verbal mediation behavior related to manual skills such as assembly and disassembly of machine-gun turrets. Recently, however, it has been used to teach descriptive statistics and is being used with other conceptual materials in an unpublished study (Stolurow and Walker, 1960). It has an advantage over the conventional, uniform size in that it saves paper by the use of the separate answer sheet. About a 25-percent saving has resulted in the materials prepared thus far. Furthermore, the booket is reusable and the learner has a convenient, complete record of his work. The instructor may want to use the answer sheets to improve the program, in which case they are convenient for data processing.

In learning a skill, the student reads each step in the book and performs it with actual equipment. After self-instruction under this standard program, the learner performs the task without the help of the booklet and under the observation of an instructor, who uses the same booklet as a guide for scoring the student, with the aid of a separate answer sheet.

In scoring, the answer sheet is inserted behind the smallest page of the appropriate assembly, e.g., behind the first five pages of a book which has five sizes of cutback pages, aligned so that the text and answer spaces match up.

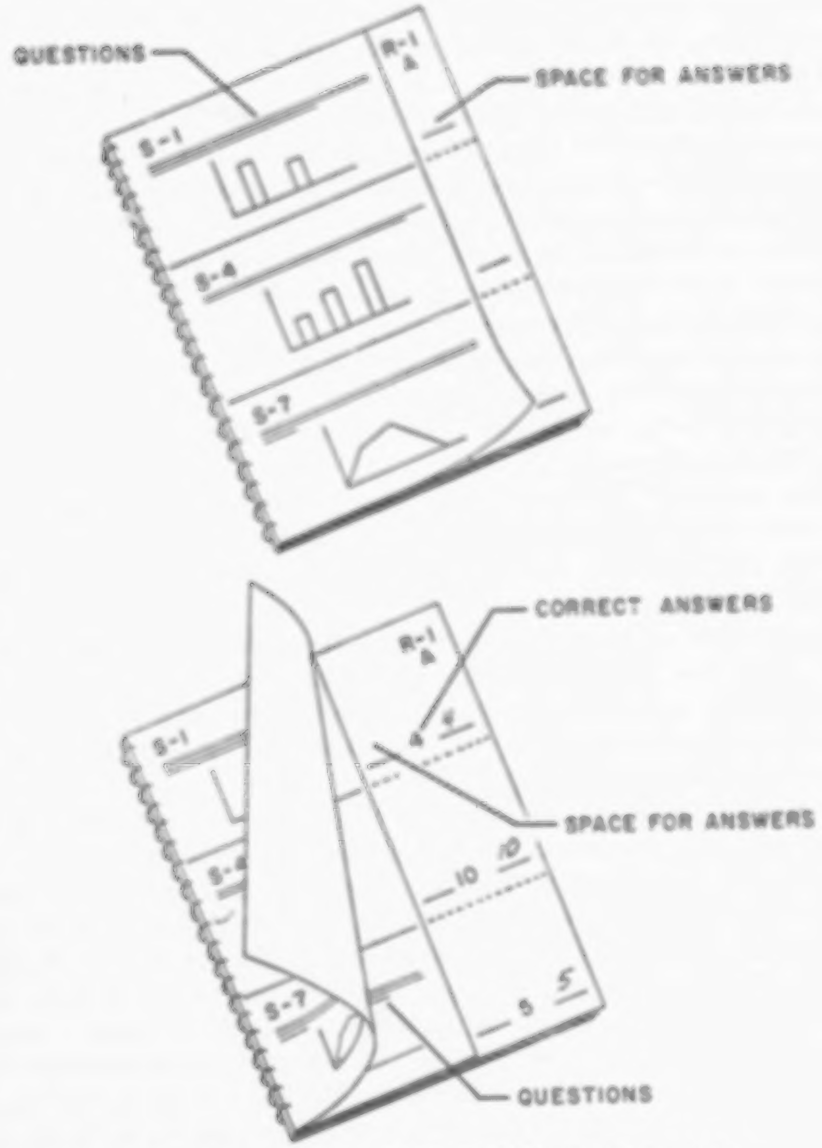

QUESTIONS
R-1
A
SPACE FOR ANSWERS
S-1
S-4
S-7
CORRECT ANSWERS
R-1
A
S-1
4 4
SPACE FOR ANSWERS
S-4
10 10
S-7
5 5
QUESTIONS

Figure 16. CUTBACK-PAGE PROGRAMED TEXTBOOK

When the cutback page booklet is used in teaching skills, knowledge of results is provided by the actual accomplishment of the step; therefore, false starts have to be corrected on the spot. In other words, these features of the teaching are provided by the equipment, not by the booklet. In teaching information, however, feedback is provided by using a split column on the answer sheet. The right half projects beyond the text page and is used to record the learner's responses. The left half of the column is covered by the text page, but it is revealed when the page is turned; thus, immediate knowledge of results is provided. Next to this information is space for recording the next answer, etc. When the task is completed, the student is given the answer sheet, which provides him with a selected, reduced set of steps on which to practice, those on which he made errors.

Another printed device is the Tab Test (see Cornell, Damrin, Saupe, Crowder, 1954; Cross and Gaier, 1955; Damrin and Saupe, 1954; Glaser, Damrin and Gardner, 1954). This device was designed originally to test the trouble-shooting (diagnostic) skill of electronics technicians. Each item in the Tab Test dealing with trouble shooting of an electronic apparatus typically consisted of 3 parts: (*a*) The symptoms of a malfunction, (*b*) a series of check procedures to determine the cause of the malfunctioning, (*c*) a list of units or components of the apparatus which might, if defective, produce the symptoms, plus some which could not produce them. A symptom of malfunction is printed at the top of the first page (the description may be 2 to 5 pages in length), where it is available to the learner at all times. Following the symptom, on the same page, is a list of check procedures and another list of units that may be defective. Next to each check procedure is a verbal description or diagram of the results which would be obtained if the check were carried out; in the case of electronic trouble shooting, voltage readings, resistance values, etc. would be included.

At the right of each unit name there is a "yes" if the unit is defective and a "no" if the unit is not defective. The student decides which one he thinks is defective and pulls the tab. If he is correct, he finds the word "yes" printed under it. For each item there is only one "yes" unit; all the others say "no" under the tab. Thus if he is wrong he must tear off another tab and continue to do so until he finds the "yes."

The material on the right-hand side of the page—this includes the check results, the yes's and no's—is covered by an opaque sheet glued to the page. The cover sheet is perforated into removable tabs which can be torn out in such a way that each reveals a single check result, a "yes" or a "no" for a particular unit. Moreover, each tab is numbered underneath with the item number as well as the check or unit number. The learner's task is to isolate the one unit causing the trouble. He reads the symptom, considers the list of check procedures, and makes a check by pulling off the tab beside that check. The solution is correct if the tab has "yes" under it, incorrect if "no" appears; in this case the student must reconsider the whole problem, make another check, and remove a tab. He continues to do this until he finds the unit tab with "yes" under it.

In effect, each set of symptoms is a problem to be solved, and the tabs to be pulled by the learner are the multiple response possibilities. Once pulled, they reveal the correctness of the response, thus providing immediate knowledge of results and a record of the learner's behavior. As typically used, the items are not sequenced to teach a task according to some concept of programing; however, it is precisely this feature which is critical if the device is used as a means of providing self-instruction. One procedure easily used as an auto-instruction device is to have the student place on a wire spindle each tab he pulls. When the set of items is completed, the spindle will have on it the numbered tabs in the order used, the record of the tabs pulled, and the sequence in which they were pulled.

The "trainer-test" (Cantor and Brown, 1956; Dowell, 1955) is another printed device suitable for a problem-solving task. For instance, in the case of trouble shooting an electronic apparatus, each student is provided with schematic and pictorial wiring diagrams and a separate worksheet, the "trainer-tester" device. The worksheet or "trainer-tester" has three major sections: (*a*) A "trouble section" describing the malfunction to be corrected; (*b*) a "symptoms section" revealing the necessary information about resistances, voltages, etc.; and (*c*) a "remedy section" providing information concerning the possible outcomes of hypothetical component replacements.

The major innovation of the "trainer-tester" is that the information in the symptoms and remedy sections is obscured from the student's sight by a silver-colored overlay. In his attempt to solve the problem, if the student wishes, for example, to "test" the resistance of a suspected defective component or to replace a component, he simply erases the silver overlay at the appropriate spot. In doing this he reveals information beneath the overlay and can then use the knowledge gained to further his problem-solving task. When the defective component is identified and the solution reached, the letters TC, standing for "trouble corrected" appear in the remedy section where the erasure has been made. During his problem-solving attempts, the student is required to number his erasures successively in the spaces at the right of each overlay so that the instructor can follow the steps taken. Here the learner provides the recorder function, and the record is collated.

ADAPTIVE MACHINES

Several adaptive machines are listed in table 4. Rath, Anderson, and Brainerd (1959) have adapted International Business Machines general-purpose digital computer, model 650, to teach binary arithmetic. This teaching-machine system allows for changes in the teaching method without requiring the building of a whole new machine; in fact, the design characteristics of the teaching machine are determined by the computer, the typewriter input, the program, and a visual output. This means that the order and the nature of the problems presented to the learner, the scoring of the answers, and the method of providing knowledge of results are included in the program of instruction to the computer. The student communicates with the computer through the inquiry station, an electric typewriter and a console capable of transmitting typed information to the computer and of receiving information from the computer and decoding it into typed form. The problem to be solved by the student is presented visually on a typed paper copy (display) through the program in the computer, by means of the typewriter. Subsequently, the learner types his answer, which is transmitted to the computer for checking. In constructing his answer to a problem, the learner must enter one unit of the answer at a time; for instance, he would compose the answer 10 by using the "1" and "0" keys. The computer in turn checks each unit immediately and types "wrong" if it is incorrect.

In view of the high speed achieved in verifying the answer (50 milliseconds to check each unit), the learner can type his answer as fast as possible until the machine signifies that he is wrong. The scoring of each unit of the response allows for the immediate isolation of the error when and where it occurs; it also prohibits the introduction of additional wrong responses. In this teaching-machine system, the learner is allowed to proceed until he makes an error. As soon as this happens, the program types "wrong" and presents new material as preprogramed. The choice of this new problem could be a function of a number of factors, the significant ones of which remain to be specified; e.g., the number of errors the student has made in this part of the program could be used to determine the next problem, which might be selected in terms of known difficulty, so that when more than a specific number of errors has been made, an easy item follows but when few or no errors are made, a harder problem is presented. In other words, the program adjusts to the learner's capability by presenting a problem of a particular difficulty level dependent on the errors the student has made.

The IBM teaching-machine system as used by Rath, Anderson, and Brainerd (1959) followed programing provisions for individual differences among learners in their skill level and rate of learning: the errors the learner is making determine whether he can skip two, one, or no problems. When the answer to a problem is correct, the machine presents a new problem. Rath et al. (1959), as a result of their limited use of this system, have indicated the difficulty that

TABLE 4.—*Adaptive automation: Critical requirements and available machines, 1960*

Adaptive machines and references	Critical requirements									
	Presentation (display)	Response	Pacing	Comparator	Feedback	Collator/Recorder	Selector	Library	Program	Computer
1	2	3	4	5	6	7	8	9	10	11
Interactive Decision Making Assembly (IDMA). Pask (1957b).	Radar scope.	Constructed (Radar control station).	Machine and learner.	Machine.	Original level; visual.	Yes/Yes.	Yes.	Extensive.	Interpretive.	Yes.
Didak 101 (Key-punch trainer). Rheem Mfg. Corp. Solartron Automatic Teacher. Pask (1958c).	Printed.	Constructed keyboard: (a) 12-key, (b) typewriter 32 key.	Learner and machine.	do.	do.	Yes/Yes.	Yes.	do.	do.	Yes.
IBM-650, adapted. Rath et al.	do.	Constructed keyboard.	Learner.	do.	Original level; visual, tactual.	Yes/Yes.	Yes.	do.	do.	Yes.

the computer is, because of its high speed of processing, waiting most of the time for the student. This might be remedied by a more efficient and now technically feasible modification that would permit the use of the computer with several different students sitting at different inquiry stations sharing the computer's time for problems and feedback.

Rath et al. (1959), have suggested the need for ordering the problems by difficulty of concept. To take care of this difficulty the computer could be programed to alter the order of the problems on the basis of the difficulty of each problem as revealed by the respective performance of each student.

The most outstanding adaptive machines—except for the human tutors—are probably those designed by Pask (1957a, 1957b, 1957c, 1958a, 1958b, 1958c, 1959a, 1959b, 1959c). The key concept behind the Pask machines is that of organic control: the teaching machine seeks a compromise with the learner, an optimum solution balancing several separate but interacting requirements. This is distinct and in opposition to the concept of automatic control, where the teaching machine tends to impose a behavior pattern upon the learner. Pask (1958c) is of the opinion that a teaching machine must function as a learning machine; i.e., the machine must learn what the student's capability is from the responses he makes and must then adjust the difficulty level of the problems it subsequently presents to that student. Pask also expresses the view that the teaching machine is essentially a cybernetic arrangement; i.e., it obeys and issues commands. Moreover, teaching is considered analogous to a special kind of conversation or to a game in which the teacher is playing with a student for two main objectives: (*a*) to find out how the learner learns; and (*b*) to improve the learner's rate of learning.

The first objective in terms of the game analogy is linked with cooperative play. In other words, if the teacher's question is too difficult, the learner is given an easier question. The second objective is linked with competitive play: the program of the teaching machine makes the task of the learner more difficult by making the problems to be solved more demanding or by limiting helpful information.

Pask (1958c) considers neither of these objectives more important than the other; he believes the two must be fulfilled if learning is to occur. It is important to note that he does not claim in any way that the game analogy is the description of a process taking place—between the measurement of the trainee's performance and the changes in the program—for either a live instructor or a teaching machine; rather it is a heuristic notion for developing a machine and a didactic program.

Pask has also explicitly made clear that when one refers, in the game analogy, to such terms as "difficulty level of the problems presented to the student," the only meaning which can be given to "difficulty" is "something which a particular learner finds difficult." In other words he is of the opinion that there is little point in building into a teaching machine either the teacher's own idea of difficulty or a scale of average difficulty. In the latter case, a measure of average difficulty—obtained perhaps by averaging the results of a series of questions presented to different learners—might not be applicable to a particular learner. Therefore, Pask's view is that a teaching machine must be aware of the difficulty of the items presented at any instant to the particular learner under consideration. Speed of response might be one factor revealing to the machine the relative ease of a problem for a particular learner.

To meet this requirement, Pask (1958c) has suggested that the teaching machine include a model of the interacting factors contributing to the difficulty of problems for the learner. The model is conceived as a dynamic one; i.e., changing because of the evolution occurring in the trainee's notions of difficulty as he learns. In other words, this model would have to be developed by the accumulation of response data as learning proceeds. The machine has to have the capability of developing this model by means of an information processing system to measure not only the difficulty value for each portion of a large problem taken separately, but also the overall difficulty of the problem. How is the measure to be performed? Pask proposes to balance the learner's response with an opposite modification.

In other words, the machine would get its information in a reflective manner, not directly. The information needed about difficulty resides in the behavior resulting from a set of properly conceived problems. The approach is to assume that the learner is limited to a certain number of decisions per unit of time and that it is necessary to maintain his level of interest without overloading him. The intrinsic nature of these decisions can vary a great deal, and an efficient sequence has to be built up by the machine as it gets more and more information from the learner. Only the way of processing this information can be preprogramed, not the problem sequence itself. In essence, the learner in responding to sets of problems adopts a certain pattern of behavior. It is this strategy of problem solving or learning that the machine must be designed to discover and use in giving the learner specific problems. The machine has to be able to develop a model of the learner's skill and method of learning.

Pask (1958c) has attempted to implement this notion that a good teaching machine must first be a learning machine; it must learn what the student's capability is before it can adjust excercises accordingly, as in the Solartron automatic keyboard trainer, also called SAKI, designed to train operators to punch information on cards. (IBM, Remington, etc.). The SAKI is illustrated in figure 17; it consists of a display unit, a control unit, and a keyboard unit identical with the one to be learned.

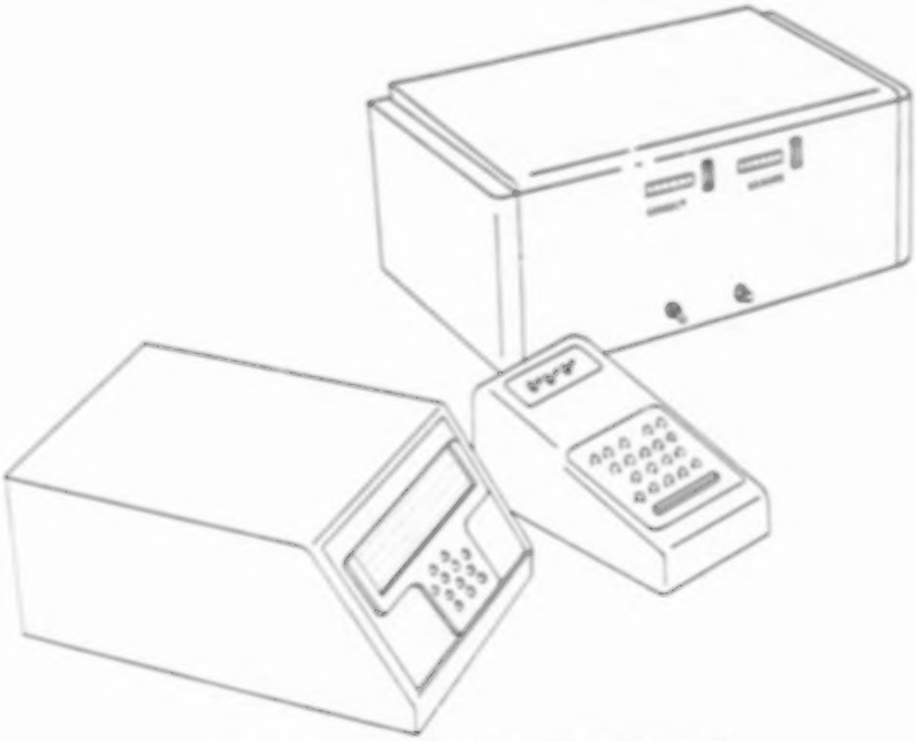


Figure 17. PASK KEYBOARD-PUNCH TRAINER

The display unit lights up successive characters on a translucent card containing 4 rows of 24 characters. At the same time, it turns on a light behind a particular position on a keyboard-like array of lights located below the card; this shows the trainee which key he is to punch on the keyboard. At first, the control unit keeps presenting the characters on the first line of the card, from left to right; moreover, the trainee is given less time to respond to the characters he has already punched correctly. As the trainee improves his performance, the lights on the keyboard-like array get dimmer and finally do not light at all (vanishing). At an appropriate threshold, the control unit presents the next row of characters on the display card. The procedure continues in this way through the four rows. The SAKI incorporates 96 condensers to check the trainee's proficiency with the 96 characters on the card; it can also make a record of the trainee's performance. In another version of the device, 3- to 6-digit numbers are used for 10-key-adding machine training.

Pask (1957a) describes an example of operational gaming using the IDMA (Interactive Decision Making Assembly) which evaluates input data without having hard and fast rules preprogramed in the machine. The decisions made by IDMA are based initially on an incomplete model in that it provides for data processing but lacks the response information provided during the operation with a learner. When two devices are used together, one becomes the teacher and the other the learner.

In table 4 some of the characteristics of available adaptive teaching machines are summarized.

CHAPTER IV

The Learner

MOST OF THE DATA from research on human learning comes from the study of groups of learners, not individual learners. The studies have provided few specific interaction effects between learner variables and methods variables, yet it is precisely this kind of information that is most useful in preparing teaching machine programs to fit the special needs of the learner. If, for example, method A helps poor learners but does not help superior learners (e.g., Detambel and Stolurow, 1956) then method A should be used with poor learners whenever possible. Interaction between a variable related to the learner, such as mental age, and another variable, one related to a method of teaching, provide the particular kind of information required for differential programing.

Two basic ideas which lurk behind the teaching implemented by machines ought to be examined in order to help clarify some confusion that now seems to exist concerning the adaptation of instruction to individual differences. Assumptions about the way one learns which have different implications for programing are: (*a*) That the learner is a receptive mechanism for whom associative connections become formed so as to mirror experience; (*b*) that the learner is a selective self-organizing mechanism who selects and extracts information from the environment.

One of the implications of assumption *a* for the method of programing is that the degree of freedom in response should be reduced. In other words, the programer should consider the learner a responsive system which has to be channeled into the formation of "correct" responses and has to be prevented from making wrong responses. From this point of view control over the learning is external to the learner. The importance of minimizing error during learning is one index of the programer's implicit acceptance of this point of view.

Acting on assumption *b* the programer allows the learner greater freedom of response through branching and the use of multiple-choice items containing the equivalent number or more wrong response terms. Thus there is less concern about the formation of wrong associations which would have to be broken or extinguished.

In addition to these differences in point of view, the concept of general ability or intelligence and its relationship to rate of learning have not been entirely clear. Many feel that intelligence and learning ability are synonymous, and that higher general intelligence means a faster rate of learning. From this assumption some infer that different programs are required for different ability levels; that fast learners will perform well on programs with a few large steps but that slow learners will require programs with many small steps. This, however, is not clearly supported by the data.

Ability of the Learner

Woodrow (1946) argues that the ability to learn cannot be identified with the ability known as intelligence. ". . . individuals possess no such thing as a unitary general learning ability" (p. 148). Ability tests predict the initial level of performance, but not the gain scores in learning tasks. The variance in gain scores on learning tasks is not correlated with general ability test scores, and general intelligence is not synonymous with learning ability. Given a sufficient ability to learn a task at all, individuals would differ, but the difference in gains would be attributable to other factors, not to general intelligence as measured by instruments such as the Stanford-Binet.

Support for this position comes from a variety of sources. Two types of data are involved: One that learning scores from different learning tasks do not correlate with each other very highly, if at all: the other that gain scores do not correlate with intelligence test scores (e.g. McGinnis, 1929).

Studies of the relationship between general intelligence test scores and performance scores on skill learning tasks generally agree in indicating that no significant correlation exists between them. Studies have been made of such diverse learning tasks as traversing a maze, hitting a moving target, overcoming effects of mirror reversals in drawing a star pattern, throwing quoits, horizontal adding, substitution, reproduction of spot-patterns, rearrangement of letters to make words, canceling letters with complex instructions, estimating lengths, and speed of tallying. Woodrow (1938) used 56 students who practiced for 39 days: in only one of these tasks did the gain score show a significant correlation with intelligence.

In examining this problem the important distinction is between (*a*) correlations of general intelligence with gain scores; and (*b*) correlations of general intelligence with achievement or final performance. General intelligence tests have significant and relatively high correlation with the initial and with the final scores (or school grades), but the correlation with gain scores typically approaches zero.

St. John (1930) has reported, however, that the correlation of school achievement (grades) and general intelligence is only 0.56, and Woodrow argues from this that factors totally uncorrelated with general intelligence have as much to do in determining achievement as has intelligence. Like the correlations obtained from experimental studies, the correlation with learning in school subjects tends to be positive but so low as to have little significance.

One interpretation of these findings is that although general intelligence test scores are an index of the level of task difficulty that the learner can master, they do not predict the rate at which he will master those tasks. Individual differences in rate of learning apparently are a function of a number of separate factors; e.g., motivation, immediate memory span, cue attention habits. Fleishman and Hempel (1956) have related scores at different stages of practice to specific aptitude test scores and factor-analyzed these correlations. They report that different patterns of particular abilities are related to the learning of specific tasks, also that with higher levels of learning (final scores) more of the variance is unique to the task being learned (specific task variance).

Memory span and age

Memory span is clearly correlated with chronological age. Retention of what is seen or heard a single time increases with age for all kinds of materials: digits, words, letters, objects, figures, and ideas in a narrative.

Both for adults and children recognition memory is easier than recall memory. While recall scores of normal children increase with age, the increments become smaller and statistically insignificant at the upper age levels of childhood; therefore, in programs for teaching machines to be used by young children it would be easier for the child to recognize the correct alternative than it would be for him to construct his response. On the other hand, the machine could require an older child to construct his response without making the task much more difficult. The method used at a particular age should depend upon the purpose of the instruction; consequently, the relative ease may be less important than the need to teach the child to write, to recite, or to draw.

Memory span may be importantly related to gains from practice. It seems reasonable to assume that each practice trial is an opportunity for the learner to acquire as much new information as his memory span will allow. If this is true, the amount of new information can be adjusted to be compatible with the known span for a particular type of material at a given age.

Problem solving and mental age

Studies of problem solving consistently reveal differences related to age. For example, deliberateness of exploration and appropriateness of the attack have been reported to increase with age. These are differences in what might be considered basic supportive or instrumental skills rather than difference in a problem-solving ability as such. The ability to solve problems might be considered to be something more.

Hazlitt (1930) takes a view concerning problem solving ability which is compatible with Woodrow's (1946) position regarding learning ability; she is of the opinion that with age no fundamental difference exists in reasoning and that apparent differences can be attributed to factors such as those mentioned.

PROGRAMING AND INTELLIGENCE

This brief review of research suggests the hypothesis that a single program probably could be prepared for a wide range of ability. Until new information is forthcoming, there seems to be no need to prepare special programs for learners who differ in general intelligence test scores, provided they are all above the minimum level required for learning the task and that adequate provision for review is made, if the program is a long one. One important research problem seems to be that of defining minimum ability for particular tasks (see Stolurow, 1960a); another is determining the relationship between memory test scores and the retention of programed materials so as to find a convenient basis for determining the optimum spacing of reviews.

Complexity

Problems frequently are complex because they require the learner to combine, or synthesize, information previously learned. Materials having these requirements would be expected to reveal differences among ability levels, and the data indicate that they do. This supports the notion that tasks have a difficulty level which requires a minimum intellectual ability. Part of the total ability requirement is explicit in the individual items of the program; another important part, the retention requirement, tends to be more illusive. Some tasks are cumulative in that each step mastered is used to master the next. Mathematics is an example; the difficulty some learners have is that they cannot retain all the skills learned earlier. This cumulative requirement is not so critical in other tasks where new associations can be made even though old ones are not retained and where there is an appearance of progress as long as learning scores alone are obtained. To reveal the complete picture, however, retention scores should be obtained, also.

In general, the ability differences reported in learning studies appear to be explicable in terms of differences in retention. As a working hypothesis, therefore, the following implication for programing materials can be drawn and should be tested: It is not sufficient to minimize errors during learning with a teaching machine program. A long program should include reviews to provide for retention differences. This can be done by using a branching program in which wrong alternatives are deliberately included to reveal the need for review. When wrong alternatives are selected, the learner should go over the review material before going ahead.

A related implication is that frequent checks on retention should be included in programs covering information and concepts that are not cumulative and interdependent (e.g., spelling). The program for these materials should not only include periodic reviews but also comprehensive examinations at regular intervals to detect losses in information taught earlier. Pressey (1950a) reports favorably on the use of "perfunctory" tests—not closely integrated with the regular instruction—which reviewed material in eight chapters the day before a regular midterm exam. Some gain resulted on the items rephrased from the practice test, and there was distinct improvement. The harder the questions on the review test, the greater the gain. Review tests can thus have both a diagnostic and a didactic effect.

Intelligence and effect of rewards

Abel (1936), using a learning task, obtained data which suggest that IQ may make a difference with respect to the effectiveness of rewards given only for improvement. He concluded that "the effect of rewards dependent upon improvement with a group of average intelligence does not seem to be as great as that of reward administered at every trial with a group of superior intelligence" (p. 50). If confirmed, this is a provocative finding worthy of further study, since it has some obvious implications for the differential use of rewards in teaching machines.

Stacey (1949) using 100 sixth graders and five methods of discovery found an interaction between amount of information, reward, and ability (p. 90). Children with high ability performed better than those of average or low ability when given minimum information; furthermore, when the amount of information was just above the minimum, rewarded children of average general ability performed significantly better than those of high or low ability. When maximum information was available, the children with high ability performed significantly better than those of average general ability, but not better than low-ability children.

These indications of the effect of interaction between intelligence and the method of providing feedback have important implications for research with teaching machines and should be investigated further.

Motivation

Motivation can be viewed as a generalized activation or "tuning up" of the learner. With increased motivation, action systems are in a greater state of readiness. A variety of external events and internal physiological processes affect motivation.

It is generally recognized that a motivated learner acquires what he learns more readily than one who is not motivated; however, research (e.g., Taylor and Spence, 1952) indicates than an interaction effect may be present. High motivation may produce more rapid learning of simple tasks but may interfere with the rate of learning more complex tasks. How does this happen? One answer is that increased motivation produces an increase in task-interfering behavior as well as an increase in task-relevant behavior. The result of a motivation condition in a particular situation depends, then, upon the relationship of negative to positive effects. This view of the way in which motivation-level and task-complexity interact grew out of the conceptualization of anxiety as a motivating state with a particular relationship to learning.

Teaching machines may produce an anxiety or motivating state different from that produced by books or the human teacher. The "toylike" quality of teaching machines may have an enhancing effect upon motivation and thus contribute to improvement in learning. Whether this toylike quality is related to novelty, a factor which may cease to exist if machines become commonplace, could be determined from long-term studies. On the other hand, the idea of working with a machine may produce fear and apprehension in the minds of some learners. If this happens, learning might benefit even though the learners might not like the machines and conditions under which they would work.

With externally paced teaching machines it is possible that the rate of presentation might affect the learner's motivation, just as it does in the classroom with a teacher or watching an educational film, etc. There probably are optimum levels of motivation associated with particular rates of presentation. On either side of the optimum, externally paced programs could produce poorer learning: "stress" effects could interfere at higher levels, external distractions at lower levels. (Enc and Stolurow, 1960)

Instructions that are part of the teaching machine program also can have motivational effects In other words, in addition to giving directions they may activate the learner. With explicit instructions to look for certain things in complex material, e.g. pictures or printed pages, the learner is most likely to select the material to which he was told to attend; and if he is only able to learn a certain amount per unit of practice, the directions can be thought of as a way in which to increase the amount of relevant learning that takes place. Myers (1913) indicates that this is what apparently happens. Errors indicated that subjects given specific instructions to attend to particular aspects of a complex printed page did not learn much about the other features of the material. With simplified materials, e.g. nonsense syllables, the amount of material available to the learner is considerably less than with textual materials; consequently, the selection of relevant material is not a problem.

Jenkins (1933) indicated that the learner sometimes instructs himself. Postman and Sanders (1946) differentiated between "explicit" instructions and "covert" instructions. They found that the former lead to the learning of different things from the latter: "explicit" instructions caused students to learn details of content, wording, and sequence; "covert" instructions brought about only general comprehension. These studies have potentially important implications for a teaching machine program: without specific instructions the learner may not select the material to which he should attend.

Recitation seems to have an activating effect. It appears to change, at least to some extent, the level of motivation of the learners; the fact that the individual is overtly responding and practicing a particular kind of behavior is an indication that he is in a more motivated state than a passive observer. In general, active participation by a learner has been found to be more effective for learning than passive reception. In fact, the most efficient practice results when more than half the time is spent in actively recalling materials. This may account for the effectiveness of the fill-in type of teaching machine programs, since they force the learner to recall material he has just read. Data also suggest that early introduction of recall with prompting is likely to be optimal. Again the machine program is consistent, for it requires recall from the beginning.

The effect recitation seems to have on learning is to some extent associated with the meaningfulness of the material. Recitation has been found to have a greater effect with disparate and less meaningful materials than with connected and more meaningful materials. This differential effect might be related to the hypothesized interaction between drive and task complexity described earlier. (See Spence and Taylor, 1951.) In other words, with disparate, less meaningful material the task is less complex in that there are fewer competing responses than with meaningful material; consequently, a higher motivation level helps in learning the complex task.

Rivalry also has been found to be an important motivating condition, particularly when the individual competes with his own previous performance; therefore it would seem appropriate to utilize this in a program. It could be implemented in the design of teaching machines: for example, by a mechanism for keeping the individual constantly informed of his progress, e.g. a counter to add the learner's score and present it to him at periodic intervals so that he could compete with his previous performance. This could be one way of maintaining an optimum level of motivation. A device for providing a graphic portrayal of the student's learning curve might be incorporated as another useful feature for implementing rivalry with himself. Either or both techniques would provide the learner with an immediate summary of his performance for the day. This information could be re-presented before the next practice session so that the learner could use it in setting a level of aspiration for himself. These procedures would be consistent with the competitive and cooperative game notions of Pask and could be built into his devices.

To the extent that tasks become more complex, i.e., involve reasoning and thinking, the motivation level should be kept more moderate for extreme motivation or emotional involvement appears to hinder productive thinking.

On the other hand, increases in motivation during learning are usually accompanied by increased resistance to extinction; thus high motivation conditions might be a means of building in resistance to forgetting. Research also indicates that things which have an apparent relevance to intelligence are remembered better. For this reason, instructions might take the form of getting the learner personally involved in the learning task, for example, by telling him that most intelligent learners make very few errors. This could have the effect of getting his ego involved. In this connection, goal-setting techniques also could be tried, to increase the extent to which the learner became personally involved in the task. A means by which the learner could record the number of errors he would expect to make on the lesson before taking it might provide valuable motivation, for in this way he could adjust his level of aspiration as he progressed.

Another means of developing motivation consistent with machine teaching is the use of discovery, which is in fact required by many of the problems posed in the program. This technique has its difficulties, since there are no objective criteria for determining an optimum "size of step" before the fact.

In general, there are many techniques which could be used to manipulate motivation effectively; in using them it seems important to consider the level of task difficulty, for the problem is to find an optimum level of motivation. The relationship between motivation and task difficulty, recognized early in psychology, was called the Yerkes-Dodson (1908) law.

In summary, available research on the relationship between the learner's ability and his gains in learning do not justify the assumption that different programs have to be written for high and low ability groups. Also, the data suggest that the clearest cases of a relationship between ability and age occur with (*a*) memory, both immediate and delayed, and (*b*) complex tasks (problem solving). However, even with complex tasks the main differentiating factors may be differences in motivation, in past experience, and in degree of familiarity or in the meaning of the symbols used rather than in problem-solving ability itself. Even for complex tasks, then, separate programing does not seem to be indicated.

It appears that rewards and feedback might have different effects upon learners of different general ability; thus studies of these variables probably should use an ability measure as a pretest index, so that the group could be stratified on ability. In the actual manipulation of motivation, several factors of potential importance need to be studied, especially task difficulty factors, as a group. The need for objective and predictive measures of the optimum motivation level for tasks of specified difficulty represents an important area for future study.

CHAPTER V

Program and Programing Process

THE MACHINES USED in the automation of instruction are only the vehicles for presenting the instructional program to the learner. Primarily they provide for an economical, convenient, and efficient means of communication and control between the program and the learner. The particular characteristics of the machine are not to be underestimated, however, for they are important in the differently described ways in which they make the content of the program available and responsive to the learner's reactions. In the sense of being an automated tutor, the teaching machine itself can be likened to the tutor's written or vocalized communication, his eyes, and, to a degree, his discriminative and decision-making functions. The teaching machine program, on the other hand, is analogous to the subject matter taught. Consequently, programing, like teaching in other contexts, consists of two sets of activities: analysis and synthesis; the former the conceptual partitioning of knowledge, information, or skills into components; the latter the development and assembly of the materials that will teach these components by building a sequence of questions or problems to move the learner along in the formation of new associative connections for the eventual attainment of a specified level of proficiency.

One can consider the communication process between the teaching machine and learner as analogous to that taking place when a student is taught with the Socratic method by a live teacher. The learner, through answering a sequence of questions, is led from one state of knowledge or skill to another. As the learner answers questions and proceeds through the program, discovery takes place. In the typical teaching machine program the learner responds frequently; he is transformed from a passive receiver into an active participant in the teaching-learning process. The extent to which the learner is an active participant depends upon the type of program and the type of teaching machine used.

In the discussion of machines in the previous chapter, it was pointed out that some features of the machines have different requirements for learner participation. The most demanding are the adaptive machines, which also have the most complex programs. It seems that the programer's task becomes increasingly more difficult as he tries to get the learner to become a more active participant in the teaching-learning process; this is probably why effective teaching is such a difficult task. It is easier to tell someone an answer than it is to ask questions and correct answers in a progressive manner.

Most teachers have experienced the need to analyze the concepts or skills they want to teach and have struggled with the problem of how to organize or sequence the parts so as to teach the concepts or skills efficiently. The Cartesian method consists of essentially these twin activities. It is a general approach useful in handling complex problems, not just in teaching. The activities are: (*a*) Analyze the problem into its smallest parts; and (*b*) proceed from the simple to the complex. This method has obvious implications for programing; however, while necessary, it is not a sufficient prescription for programing because of its failure to explicate the second activity.

Definite rules of manipulation are needed if programing is to be a scientific activity rather than an art. There is also need to have principles that will permit the development of an efficient and effective teaching sequence out of the critical parts. Therefore, other principles of organization are needed to provide technical specificity. One source of such principles is logic; another is contemporary psychological research.

Both will be examined in an effort to determine how each might contribute to efficient teaching machine instruction. While it has been shown that man does not always behave logically and that many psychological factors contribute to these departures, it nevertheless is true that the development of a concept or skill through logical induction could be an effective, if not the most efficient, method of organizing it for teaching purposes.

In the absence of verified psychological information, a logical principle might be a good interim basis upon which to program. Toward this end it might be useful to review briefly the logical principles that could be used in programing.

PRINCIPLES OF LOGIC

John Stuart Mill (1892) made explicit the basic forms used in logical induction. Five were identified and have potential relevance in programing for a teaching machine. In fact, some probably have been used without conscious effort simply because they seem to fit. What is needed, however, is an experimental check of their relative effectiveness as teaching strategies.

Method of difference

With the method of difference the program would use both instances in which the principle in question was present and instances in which it was absent, both types being presented so as to permit ready contrast between them. For example, in teaching phonetics a particular letter (or letter combination) associated with a specific sound would be presented. To illustrate that this particular letter (or letter combination) is associated with the sound, instances in which the letter (or letter combination) was absent also would be used. With this method the positive and negative instances should be presented in sequence or simultaneously. The positive instances might be more informative to the learner than the negative ones, however, since there is usually only one way of being right but more than one way of being wrong.

Method of agreement

With the method of agreement the program would consist of two or more instances, grouped in succession, in which a particular concept or principle occurred. Variations within the positive instances would be sequenced in such a way that the common thread or idea would become salient to the learner. The use of this method would involve dealing with variations within instances. Thus each set ought to be organized so that all those making the same point occur together in the sequence, one after the other.

Joint methods of agreement and difference

The two preceding methods could be combined to program a concept or skill. For instance, the program could contain a block of instances where a particular response, principle, or concept common to the sequence is first presented to the learner: agreement. It would then be followed by a block of negative instances, for which the response, principle, or concept is not applicable: difference. The method would proceed from agreement to difference. There is no logical or empirical reason, however, that would necessarily imply and justify this order. Nevertheless, this is a definite problem that could be studied.

Method of concomitant variation

The foregoing methods treat only the situations for which the absence or presence of a phenomenon is critical. They permit one to manipulate materials so as to make it apparent to the learner that a particular difference exists due to the presence or absence of a specific factor, typically a cue stimulus.

The method of concomitant variation, on the other hand, is a method of correlation. With this method the cue material is something with which the learner already is familiar in the sense that he can readily recognize variations that have something in common. Such variations among stimuli as their size, brightness, or intensity are familiar examples of continua to which learners respond as members of a set. The variations within the set, provided they are large enough, are detected by the learner. Tabular arrangements of numbers can be presented in this way so that the increments in magnitude in one variable (e.g. column) can be related readily to variations in another variable (e.g. row). Psychologically the difference is one of seeing the variations within each set as belonging to the same class or set as points on a continuum. As long as variations are seen as discrete changes, they belong to the method of concomitant variation. When variations are seen as variations within a set (e.g., the letters within a word), the changes do not fall along a continuum and therefore become an example of a previously described method.

Method of residue

This method lends itself to use when it is the intent of the programer-teacher to induce a discovery experience. A complex perceptual display or a complex concept is gradually reduced so that the individual is led step by step to eliminate particular components of the complex situation or cue with which the phenomenon or concept of interest is associated. The learner is gradually presented with situations rich in apparently relevant possibilities. These possibilities are eliminated one by one until the learner is finally left with the "residue," the final relationship, which emerges as a discovery experience as a result of careful programing to eliminate the erroneous possibilities.

Symbolic logic

Rapid advancements have occurred in recent years in the development of symbolic logic as a tool for analyzing both mathematics and nonquantitative ideas. It is likely that this tool will serve as an exceedingly important means of analyzing programs for teaching machines. Through the use of symbolic logic it is possible to examine the general form of subject matter in order to reveal its basic structure. This is one way to determine from the analysis of content whether a part of one subject matter is similar to another very different subject matter.

To the extent that these isomorphisms can be identified through symbolic logical analyses, comparative studies can be made to determine whether the semantic differences are the critical factors or whether the syntactical differences are more important in determining the nature of an effective program. If it should be the syntactical factors, then research on variations in structure would be an important independent variable for research on programing in teaching machines (see Stolurow and Newman, 1959).

PRINCIPLES OF PROGRAMING

Task factors

As indicated earlier, the twin processes in programing are analysis and synthesis. In the first process, there is the problem of determining what to look for in making an analysis. Not all the features of a task make a difference with respect to the rate at which it is learned. Thus the problem is to find a set of intrinsic objective features of tasks that give an advantage to the programer in allowing him to make, in advance, useful decisions about both the partitioning of the subject matter and the way in which it is to be handled in the program to produce efficient learning.

Unfortunately there is no completely satisfactory classification system either for tasks in general or for learning tasks in particular. This is an important but heretofore neglected and unsolved problem in psychology. Now, however, there is beginning to be some evidence of a systematic effort (e.g., Cotterman, 1959) which it is hoped will produce the type of classification system that will be useful in the educational programing of subject-matter areas and related complex learning situations.

Cotterman has pointed out a type of criterion which might be useful in task classification; namely, whether the task characteristic produces an interaction effect with a practice variable. If, for example, massed practice produces more rapid learning than does distributed practice with tasks of type A but not for tasks of type B, then these two tasks differ in some fundamental way. The problem for the researcher working on the development of a task classification system is that of determining the way in which they differ. To do this he needs some hypotheses about critical differences in tasks. Together the criterion and the set of hypotheses provide a strategy for the development of a task-classification system for learning tasks.

The five following characteristics represent one set that appears to interact with methods of teaching and/or characteristics of the learner to differentially affect performance scores. These features of tasks might be useful in analyzing them to determine the way in which the material is to be programed for a teaching machine. These characteristics have been described in greater detail, and some of the supporting evidence for their consideration has been reported in two of the author's unpublished papers, one of which was presented at the 1960 APA meetings (Stolurow, 1960b, 1960c).

1. *Number and sequence:*—The simplest learning task involves the association of one cue-stimulus with one response, e.g., a face (cue) with a name (response). If we want the learner to say the name when he sees the face, the sequence of presentation should be face—name and not the reverse. If we want the child to say a word when he sees it printed (e.g. on a card), the sequence of presentation should be the word followed by a familiar picture of the object represented, not the reverse. This is the analog of conditioning, The word is the "cue-stimulus," or *CS*, and the picture of the face is the eliciting stimulus or response producer.

It is critical in programing to identify both cue-stimuli and response-producers and to arrange them in that order. This is intra-item sequencing. While the fundamental step in analysis is that of determining the intra-item sequence, the fundamental step in programing is not so clear. However, there are some data which suggest that in programing, the prompting sequence might be more efficient for learning than the confirmation sequence (Cook and Kendler, 1956). In the prompting sequence the learner first sees the cue-stimulus, then he sees the prompt, and finally he makes the response. In the confirmation sequence he also sees the cue-stimulus first; but he makes the response next; and after he makes it he sees the confirmation (called the prompt when it appears before, rather than after, the response). An unanswered question, now being studied, is whether prompting also is better for retention. The writer's preliminary data suggest that confirmation may be better for retention.

When there is a set of S–R's rather than just one to be learned, different inter-item sequences can be used in presenting them to the learner. This possibility results in a basic difference between tasks, the relative stability of the inter-item sequence from one trial to the next. With a stable inter-item sequence, such as the order of letters in memorizing the alphabet or the sequence of cities along a route on a map, the task has predictability. The learner can predict what his next response will be in a stable inter-item sequence task such as these. However, with a variable inter-item sequence task such as learning pairs of English-French words, predictability is limited to the association of a cue with its response. The learner cannot anticipate the next cue and consequently cannot anticipate his reponse. In effect his reponses are dependent upon, or under the control of, individual cues which may appear in a variety of different sequences.

The stable sequence task is often called the serial-learning task, and the unstable one the paired-associates task. The former is learned faster than the latter. For a given number of items in the program, the learner will master more if the sequence is kept stable than he will if it is varied. (See McGeoch and Irion, 1952, for an explanation of the way serial learning is thought to be achieved through the formation of remote as well as adjacent associations and the development of cue-producing responses.)

However, if the program is written so as to stabilize a sequence of items like the alphabet, then the habit system which will be developed in the learner will have both advantages and disadvantages. The habit system is simply the set of associative connections established through practice, the set of stimulus and response connections known to exist. One advantage of a serial habit system known from experience in using the alphabet is that an item can be easily supplied when it follows a given item in the set. However, a limitation and potential disadvantage is the unidirectional character of the associations as demonstrated by an effort to start with Z and go to A, or to count backwards from 100 by sevens, for example. All ordered sets of relationships, or serial habits (e.g., scales in music, number series) are like this; the reverse order has to be learned as a separate task. To achieve each set of serial associations, it is necessary to practice the sequence in a stable order and it is easier to learn the material if the order is preserved; consequently, variation should be introduced only if there is some particular reason for it.

If the number of associations is small in relation to the memory span of the learner, the amount of practice required may be as little as one trial (see Dietze and Jones, 1931); however, with increased length, repetitions are required. The Kjersted-Robinson law states that the proportion of material learned during corresponding fractions of the total learning time is relatively constant for different lengths of the same type of material. Whether it holds over a relatively broad range of different lengths is not known for sure, since

Lyon (1914) found a curvilinear relationship between length of material and trials to learn it, when he used variations in length from 8 to 300 pairs of syllables (unstable sequences). Learning tasks with a stable sequence, however, tend to show an increased level of difficulty with increased length sooner than do paired-associate tasks; e.g., Lyon's data on serial learning ranged from 0 to 72 items in length and showed a marked departure from linearity. Less departure from linearity appeared with poetry, however. This suggests that meaningfulness also interacts with length and sequence stability to differentially affect performance. Thus, the sequence stability of a learning task may interact with its length to determine the amount of practice required to achieve a particular level of mastery. Furthermore, the meaningfulness of the material also may be a factor that interacts to produce a differential effect.

In relation to programing, it appears that the programer should take very different courses of action according to the number and sequence characteristics of the task to be taught.

The specific implications of each task characteristic will be discussed later. At this point the characteristics should be made clear so that the programer might have some useful guidance in identifying critical task characteristics.

As the number of items exceeds the memory span of the learner, it is necessary to build redundancy or repititions into the program to allow all of it to be learned. The programer has basically two choices: either to repeat the same item or to introduce some variation.

2. *S and R limits.*—The second provisional task characteristic is the extent to which the cue-stimuli and responses are broadly or narrowly defined. If, for example, the cue-stimulus is broadly defined in the sense that from one time to the next variations in it occur, the learner must discover the critical components, and this requirement slows down the rate of learning. On the other hand, if the response can vary from time to time so that it need not meet very restricted tolerance limits, then learning is typically easier and improvements in performance go on more rapidly. Thus broad stimulus limits can impede learning, but broad response limits can accelerate it. Here the concern is with the stability or reliability of stimulus and response limits.

Limits also are important in another sense; namely, in their similarity. Some stimuli are more confusing than others; that is, individuals will behave toward them as if they were the same. Either S_A or $S_{A'}$, can be used to cue a response if they both are judged to be similar, and therefore one way of expressing similarity is in terms of common elements. One kind of similarity is perceptual, as when two faces are confused because the details are very much alike; another kind is mediated or acquired similarity, as when two different things are confused because they have been associated in previous experience with the same response or set of responses. Both kinds make for slower learning if the individual must now differentiate between two similar things and behave differently toward them.

The limits defining a cue-stimulus or response are not independent of the particular set with which they occur in a task. A particular shade of pink as a stimulus by itself may be readily used as a cue. However, if a child is learning color names and is presented with patches that are to be called crimson, pink, cerise, and salmon, the task may be much more difficult. In making a judgment about the limits of task stimuli and responses, it is necessary to examine the complete set to be learned.

When stimuli that are maximally different from one another are placed together, the limits are more broadly defined than when those same stimuli are rearranged so that the ones most alike are grouped together. In the latter case the limits are narrowly defined. In general, broad limits produce more rapid learning, (e.g. Rothkopf, 1958). This is not surprising in that from one point of view "broad limits" simply means that one response to a larger range of stimulus variation is acceptable in meeting the program criterion.

3. *Meaning.*—The characteristic of tasks which we describe as meaningfulness can be objectively related to the learner's available responses. The responses which are available to task stimuli appear to have three related, distinguishable aspects that pertain to learning: (*a*) Orderability; (*b*) presence of one or more dimensions of association; and (*c*) the associative significance of the responses; i.e., whether the responses are at the level that is required or useful for the amount of learning to be achieved.

To illustrate orderability consider the many generalizable serial associations which individuals take from one learning situation to another; for example, the alphabetical and the numerical sequences (e.g., counting by ones, twos). In a new task that may elicit them, these generalized habits are either an advantage, if they are compatible, or a disadvantage if they are not and consequently the stimuli or the responses for this characteristic could relate to rate of learning. The presence (or absence) of a dimension of association seems to have implications for rate of learning. If present, such a dimension could aid or interfere with learning, depending upon the way it related to the task to be learned.

As for the associative significance of tasks, consider a genetics program intended to teach the definition of the word "phenotype." The learner's response that is available at the start may be to pronounce the word. Consequently, it is necessary to substitute another response, since the available one is not at the level required. This lower-level response may or may not be useful in learning the desired response. To illustrate what is involved it is necessary to consider the notion of mediation (see Osgood, 1953).

A variety of studies suggest that mediation processes are a necessary concomitant of learning. Most simply, a mediation process is a two-sided event: It is implicit (internal), and it serves to link two independent experiences together. For example, if the experiences are symbolized by S_1–R_1, for the first association, and S_2–R_2 for the second association, then consider the relationship between R_1 and S_2. If these are completely independent events, then there is no mediation possibility. On the other hand, if R_1 provides cue-stimuli which are related to those provided by S_2 then mediation is possible, through generalization. A variety of techniques have been used to study the possible ways in which mediating linkages are formed. In general, it appears that response-produced cues, perceptual cues, emotional (e.g., fear) cues, and verbal cues serve as mediators. With respect to the response-produced cues, two or more very different stimulus events may elicit the same attention habits and, to the extent that they do, the attention habit could serve as the mediator.

An available response which is at a different level from that required by the program, nevertheless, may be a mediator or connecting link between two separately experienced events. The logic of this can be illustrated by the following. A child is taught to say "Now" when seeing a light flash (Light="Now" or A–B association), light symbolized as A and "Now" symbolized as B. Then he is taught to move a handle on a teaching machine when the teacher says "Now" ("Now"=handle-moving response or B–C association). Following this the child may be taught to move the handle (C) when he sees the light flash, forming an A–C association. Since he learned the first two steps (A–B and B–C) he would be expected to learn very quickly this last step—to turn the handle when he heard the teacher say "Now". The sequence of S—R's can be represented symbolically as follows: A→B, B→C, then A→C. In this example, the response represented by B (e.g. saying "Now") serves as a mediator. Note that the sequence used in teaching was set up so that the response that would serve to mediate was first learned as a response and then as a cue-stimulus for another response. In this way it acquired two functions: (*a*) A response to an explicit stimulus, and (*b*) a cue for the desired response.

Pronouns are examples of a class of mediators which serve to establish remote associations in prose. They serve a catalytic function. For example, two sentences read as follows: "John is feverish. He is shaking." The connection between the subject of the first sentence and the predicate of the second sentence comes from the existing "meaning" of John, its capability of eliciting the response "He." *This also illustrates mediated learning. The paradigm in terms of* the S–R pairs represented symbolically is A→B, C→D, then A→D, and since in the example using "John and he" the A→C link existed as a result of past experience, the A–D association occurs without explicit practice. The resulting association is A→C→D. Here the pronoun (represented by C) serves as a vehicle for establishing an unpracticed association.

A component response differs from a mediator in that it is a response that combines with another to form a larger response. For example, if in teaching the concept of theism the program went on to teach monotheism and polytheism, it would be utilizing theism as a component response.

Both the assembling of new combinations of components and the establishment of new connections through mediators are methods of producing meaning. In simplest form, meaning can be defined as the existence of associations. Each association that exists can serve as either a component response or a mediator in establishing new meanings. Consequently, the number of existing responses to a stimulus is an index of its connotative meaning. The utility of connotative meaning is determined by the new learning situation; it is the relevent meaning. Some meanings help produce new learning and others interfere with the formation of new associations.

What are the implications for programing? Techniques such as the semantic differential (see Osgood et al., 1957) could establish the incongruity, if any, between the learner's meaning and the intended meaning, prior to practice on the learning task or the preparation of a particular program. Then the discrepancies could be studied in terms of their relationship to ease of learning, for example. This type of study could provide useful data related to programing.

Having a large number of meanings (responses available) on a sheer statistical basis could increase the probability that either the desired component response or useful mediator would exist. Consequently, a crude but possibly useful index of meaning might be the available number of responses (Noble, 1952). More precision is probably provided by knowledge of the type of established responses (Osgood et al., 1957) available to the learner. Having a large number of responses may not be an advantage over having the right one. However, since stimulus-response relationships in a subject matter are not random, an increased number (a web of associations) is more likely to mean that there is a greater probability that a useful response exists in the learner's repertoire.

When the stimulus or the response, or both, are members of an orderable set, then certain meaning possibilities are increased. Instead of just having a noun-pronoun association available as a basis for mediation between two associative links, in an ordered set there exists a whole group of stimuli which automatically acquire the capability of eliciting a response deliberately associated with any one of them. Ordered sets typically have established both adjacent (e.g., in counting between 1 and 2 and 3, etc.) and remote associations (e.g., saying every other number). While an ordered set is a homogeneous set, some homogeneous sets are not orderable. Consequently, homogeneity or class membership and orderability represent variations of significance in describing the meaningfulness of tasks to be learned. These factors appear to determine the transferability of associations.

4. *S-R linkage pattern.*—The learning task that is programed, or a portion of it, may be designed to develop (*a*) one-to-one, (*b*) one-to-many, (*c*) many-to-one, or (*d*) many-to-many linkages between stimuli and responses.

The first of these is illustrated by pairing object and name; e.g., "the center of a cell is the nucleus." The second is illustrated by a program sequence teaching a genus-species relationship or a class-instance relationship. The third is the reverse of the second. For example, teaching the learner that 2+6=8 and that 3+5=8 illustrates a many-to-one S–R linkage pattern—2+6 and 3+5 are two separate cue stimuli to which the learner is to make the same response—saying "eight". Teaching symptom-cause relationships in either medical or engineering diagnosis is an example of the many-to-many S–R linkage. Typically diagnostic information is characterized by a set of symptoms related to a set of possible causes (e.g., Stolurow and Bergum, 1958).

In preparing subject-matter programs it will be necessary to implement all of these S–R linkage patterns. They will be found with varying frequency in different materials. Seldom will there be a program in which all the elements will be related according to a single pattern, e.g., one-to-one.

It is useful to analyze each linkage arrangement, since this information can assist in the development of an efficient program. Mapping the S–R relationships to be formed leads to cogent programing and the deliberate association of each cue and response term in the way required for optimum criterion performance. The task factors just described are summarized in table 5.

TABLE 5.—*A provisional set of critical learning task characteristics*

TASK CHARACTERISTICS	VARIATIONS WITHIN CHARACTERISTICS[1]
Elemental (S and R)	
I. Number and sequence	A. One, no sequence
	B. Two, invariant
	C. Two, variable
	D. Three or more; invariant
	E. Three or more; variable
	F. Number unspecified; specifiable in duration (invariant)
	G. Number unspecified; specifiable in duration (variable)
II. Limits	A. Broadly defined
	B. Narrowly defined
III. Meaning	A. Unorderable; with associative significance
	B. Unorderable; without associative significance
	C. Orderable on one dimension, and with associative significance
	D. Orderable on one dimension; without associative significance
	E. Orderable on more than one dimension; with associative significance
	F. Orderable on more than one dimension; without associative significance
Relational	
IV. Pattern of linkages	A. One-to-one
	B. One-to-many
	C. Many-to-one
	D. Many-to-many
V. Input-output homogeneity.	A. Homogeneous
	B. Heterogeneous

[1] Combinations of separable characteristics are used to reduce the number of combinations to a minimal set of tasks.

5. *S–R homogeneity and compatability.*—If the task required the learner to form associations between pictures as cue-stimuli and words as responses, the set of relationships would be heterogeneous; the stimulus terms and the response terms would be homogeneous, but since pictures and words are drawn from different populations of stimuli (e.g., Lumsdaine, 1949; Kopstein and Roshal, 1954) the task which uses them as described requires the formation of a heterogeneous set of relationships. If, instead, associations were to be formed between pairs of English words, the linkages as well as the stimulus and response terms themselves would be between homogeneous sets.

S–R compatability, on the other hand, refers to the relationship between elements of two ordered sets (e.g., number as cue-stimuli and lengths as response producers) where both increase or both decrease (Fitts and Deininger, 1954). S–R incompatibility, on the other hand, refers to situations where the elements to be paired from two ordered sets do not vary in the same way; for example, one may increase while the other decreases, or one may increase while the other varies randomly.

Heterogeneous unordered sets are generally learned more rapidly, possibly because fewer interfering associations exist (e.g. Lumsdaine, 1949). Also with them it is possible to organize material so as to allow the learner to use class-descriptive cues as well as item cues (Wulff and Stolurow, 1957). A class-descriptive cue is one that is common to some but not all cue-stimuli in a set to which different responses are to be learned.

Compatability also aids learning, since the learner can make use of existing meaning. Incompatability or lack of congruence between stimulus and response sets, on the other hand, permits meaning to act against the new learning. If, for example, the cue-stimuli are ordered in the clockwise direction and the responses counter-clockwise, the two are incompatible, heterogeneous unordered sets.

The characteristics of learning tasks just outlined provide one approach to the analysis of materials to be used in teaching. In analyzing materials in terms of the criterion behavior desired, this set of characteristics would be inventoried, and for each entry in table 5 a question would be asked of the material. First it is necessary to identify the cue-stimuli and then the response producers. When they are collated so that with each stimulus there is at least one response producer, then their number is known and it is appropriate to formulate the sequence questions, etc. In this way an objective description of the task can be obtained which is free of content or semantic reference. Thus the formal relational characteristics can be considered in organizing the program according to programing principles.

The remaining part of this chapter is an attempt to identify from among the many procedural variables studied in the educational psychology laboratory, some which may have a useful relationship to the task factors described. Doing this could provide information of use to those wanting to use the Cartesian method in programing. Some of the potentially pertinent psychological research relating to these task characteristics is briefly summarized in the pages that follow.[1]

Practice conditions

Stimulus factors.—The sensory modality through which stimulation enters, although it is necessary for learning, does not appear to make much difference in the rate of learning. Differences, when found, usually can be attributed to some other factor.

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[1] The task classification system and related material were developed under a project sponsored by the U.S. Air Force, Air Research and Development Command, Wright Air Development Center, under A.F. Contract 33(616)-3965, monitored by C. E. Cotterman, Training Psychology Branch, Behavioral Sciences Laboratory.

Variations within a particular modality, however, may have an effect on learning efficiency. A single outstanding item in an otherwise homogeneous series, for example, will tend to be learned more rapidly than the less outstanding members of the series, regardless of its position. However, the initial effect of isolation appears to be to make the to-be-associated response more likely to occur. With additional practice it becomes attached to the appropriate cue. Isolation, or vividness, may be achieved through difference in color, size, italics, underlining, etc.

If the program is designed to teach one-to-one relationships (paired-associate learning) such as objects-names, names-dates, cities-states, etc., these associations appear to be formed more rapidly when: (*a*) the more familiar or meaningful one of the pair is in the response position (Sheffield, 1946), and (*b*) the simpler one is in the response position (Stolurow and Bergum, 1958).

Materials sometimes permit the programer the flexibility described with respect to the use of one or the other of the to-be-paired stimuli as the task learned first. For example, it is possible to begin the program in French with an English-French vocabulary or to begin with a French-English one. However, since the teaching objective is to make the learner capable of translating in both directions, the only requirement is that both directions be used in training. This means that the programer can select either one to begin with, and that he can follow it by the other. In such situations the more complex or more difficult member of the pair, the more unfamiliar one, should be placed in the cue-stimulus position (e.g., French-English for English-speaking students). Cognates are good in beginning a foreign vocabulary, for the learner can make responses at the desired level. After he has mastered a set of vocabulary words, he can switch to the reverse direction of association, e.g., English-French. Programing to take advantage of differences in the rate at which the different directions of association are learned can be managed by having the learner master sets of words to a particular criterion before the direction of association is reversed. The best criterion level to use is not known, but it is probably better to err on the side of overlearning the first direction; errorless performance should be required at least once and possibly two or three times.

Response factors.—Each stimulus is correlated with a response, and in this sense the stimulus can be said to be the producer of that response. In programing it is essential to know what stimuli are capable of producing the responses to be taught. In the analysis of learning tasks it is important to start by asking what responses the person should be able to make when he meets the particular criteria of acceptable final or criterion performance, then to know what stimuli are correlated with those responses. These stimuli are the response producers. The next step is to determine what will be the cues for these responses in the criterion performance—when should each response be made. Then the program is designed to achieve this matching.

For most school learning situations, language serves as the response producer, although pictures and demonstrations are also used, particularly in the lower grades. In the upper grades verbal instructions become the principle response producers.

Three characteristics of stimuli used to produce a response are important: (*a*) Reliability (the dependability with which they can produce the desired response); (*b*) speed of elicitation (the latency of the response); and (*c*) precision (the correspondence of the elicited response with the demand of the new task).

With increasing levels of complexity, simple response elicitors are combined to form compound responses. Often the programer's problem is one of eliciting a response which satisfies a particular criterion. Where response precision is difficult to achieve initially, however, the programer can plan deliberately for the occurrence of responses which will only approximate the ultimate criterion. In fact, it may be necessary to start a program by simply reinforcing responding of the type desired, e.g., saying something. As the desired type of performance increases in its output, selection can be made from among the responses. By progressively modifying standards in providing feedback, the behavior can be "shaped" to meet the ultimate criterion (Skinner, 1957e). This should be a deliberate process, not left to chance.

Changes in motivation, e.g., through the production of stress or anxiety, sometimes are used to increase the type of response desired. This and other forms of stimulus manipulation are used to bias responses in a particular direction. Machine pacing of the program may be used occasionally to increase the response rate above that which otherwise would occur. If performance at slow speeds is the same as at high speeds, then training can well begin with emphasis on the accuracy of the response, provided the base rate is already adequate. This can be followed later by further increases in pacing to bring the rate up still further.

Pacing, however, may be a double-edged sword. Transitional rates should not be maintained for long, lest a speed set be established and become hard to change. If the behavior changes drastically with increases in speed, and high-speed performance is desired, slow speed should not be used. External pacing can work either for or against the programer's purposes. In other words, if pressing responses are made at slow speeds and ballistic ones wanted at high speeds, then practice at slow speeds, particularly if prolonged, may make it more difficult to change the response; and movement to high speed may be slower than if the learner had started with the correct responses to begin with.

With respect to these practice conditions, it seems more likely that the sequence within a particular subject-matter area might be to teach the concepts first and to follow them by programs which require construction of responses and utilization of the ideas, principles, and concepts that were taught. Thus the sequence would be concept, then the use of the concept and the construction of the responses desired when the concept is employed. For example, the concept to be taught might be the sign test in a statistics program. The concept name, since it is new to the learner, would be the cue-stimulus or subject of a sentence; consequently, the response term or predicate would be the more familiar term; e.g., the sign test is the name of a statistical test that uses plus and minus signs instead of numbers. Each step would relate to the concept supplying the learner with a set of one-to-many associations. The "sign test" as a cue-stimulus would be associated with a number of responses which collectively define the concept. Following this, the concept would be used in simple examples.

Learners who verbalize a task while learning it (e.g., a motor task) tend to learn faster than those who use visual imagery or kinesthetic cues. Consequently, it appears that in programing the learning of a skill it would be useful to employ verbal responses, e.g., spelling, in early stages and in the development of the skill. Later the motor aspects of the skill, e.g., printing or writing, could be programed. For some learners combining these separable responses into a single program might be efficient, since they would thus verbalize and write at the same time.

Feedback factors

Feedback is provided by stimuli which reinforce the response immediately. Generally speaking, a reinforcer is any event following a response that increases the probability of that response the next time the cue-stimulus is presented. Performance in a learning task is said to be shaped by its consequences. Delays of reinforcement or knowledge of results are critical factors in programing because of their effect upon learning. Reinforcing stimuli rapidly become less effective as the delay increases between the response and its reinforcement.

Reinforcing stimuli can be considered as events that punctuate experience; they produce an abrupt change or shift of attention to a new cue. Different stimuli may perform this function with varying degrees of efficiency. Some of them not only punctuate but also provide knowledge of results: they tell the learner whether or not his response was correct.

Frequently combined with knowledge of results are stimuli that specifically redirect the learner's attention. Simply telling the learner that he is right or wrong has an important effect upon subsequent rate of learning, but it is not the whole story. When there are many ways in which the learner can be wrong, the knowledge that the response was right is useful but knowledge that it was wrong is not.

If, after a wrong response, the learner is told what the right response is, that information is not simply a reinforcement; it is actually an elicitor, a prompt. Its function is to elicit either the correct response or a surrogate in the form of a verbalization on the part of the learner. If the response takes place in the presence of task cues, it becomes associated with them. If, for example, the child responds by saying "ten" to the question of how much is 7 and 4, and he is then told the answer, it makes a difference whether this feedback is programed one way or another. It is more efficient to program knowledge of results by restating the problem along with the answer. For example, the program might tell this child, after a wrong response, "7+3=10." It would not be as effective to simply give the answer without the problem since "7+3=?" the cue-stimulus, would be missing. When the learner is given the answer the cue-stimulus also should be given so that the two can become associated.

As Skinner (1959) has pointed out, one of the main problems in school learning situations involving groups of children is the sheer impossibility of providing consistent reinforcement. A teaching machine program, however, can do this and do it in accordance with the most effective principles of reinforcement. Each learner is working by himself with a teaching machine, but in a classroom one teacher is trying to help several students simultaneously.

While consistent (100 percent) reinforcement leads to more rapid learning than inconsistent reinforcement, it may not necessarily be the most effective condition for the retention of some responses; therefore it might be useful to investigate the effects of a mixed strategy of reinforcement on retention of specific responses. A 100-percent reinforcement schedule in a teaching machine might be employed to get the behavior up to a predetermined level, e.g., above 75 percent correct. Following this, partial reinforcement might be built into the program. Techniques for programing such a transition in the consistency of reinforcement need to be developed. Testing, interspersed between training sessions, is one way of varying the reinforcement schedule, since in testing there is no immediate feedback and the test may not be collated with each cue-response unit but rather given as a total score. Procedures such as this seem to be worth examining in view of the apparent resistance to extinction which follows partial reinforcement. The wording of instructions would be an important specific problem in this connection since one condition determining the effect of reinforcement is the extent to which the reinforcing event relates to the motivation of the learner. The instructions could provide this relationship.

Time factors

Several time intervals are critical in determining rate of learning. Two intervals facilitate learning when they are minimal; and two others facilitate learning when they are optimal. Efficient learning requires minimum intervals between (*a*) the cue and response, and (*b*) the response and reinforcement. Optimum intervals are desired between (*a*) a reinforcement and the next cue-stimulus, and (*b*) practice periods with a particular set of materials.

Research on the effectiveness of distributed practice has produced no simple principle for use in programing. The data indicate that one cannot make the decision to mass or to distribute practice simply on the basis of whether the material is verbal or motor, for example; although both verbal and motor tasks benefit from distribution, there are exceptions. Possibly a more useful task distinction is between serial and paired-associate types of tasks. Distribution of practice is better in learning serial tasks than paired-associate tasks, and massed practice produces better retention with serial tasks than distributed practice; however, distributed practice produces better retention for paired-associates tasks.

Much of the existing data relating to distributed practice in school subjects has been obtained from learners who memorize prose or poetry: serial learning. Distinguishing between verbatim (serial) learning and idea learning may be useful in relating the data to programing.

The apparently greater effectiveness of distributed practice for verbatim, serial learning does not indicate that distributed practice also would be better for learning ideas. In fact, rehearsal is sometimes offered as an explanation of the greater effectiveness of distributed over massed practice. This implies that the idea is learned before the verbatim sequence; otherwise, how could the learner rehearse. This is supported by other data and in addition reminiscence effects are different for both idea and verbatim learning. At most, rehearsal may contribute to the benefits of distributed practice, but it cannot explain them.

Apparently for many tasks it is necessary that the learner establish "a set" or orientation for the task to be learned. These data suggest that in programing it might be useful to introduce as a preliminary part of the program a sequence that provides a set: an organizer of the fourthcoming material. This part of the program would be a way of establishing a set which might aid in learning the program to follow.

Whole or part learning

McGeoch and Irion (1952) describe the three classical part methods:

1. Pure-part method
2. Progressive part method
3. Repetitive part method.

With the pure-part method each part is first learned separately to a criterion of mastery, then the parts are repeated in proper sequence until the whole has been brought to the criterion already achieved by each part. The two steps are: (*a*) Learning the parts separately to a criterion; and (*b*) linking the parts together.

This method is related to the use of the correction procedure, for with the correction procedure the learner is required to make the correct response before he is allowed to go on. Pressey, Skinner, Porter and Stolurow, for example, in building this feature into their teaching machines (see ch. III) are acting as if the pure-part method is optimal. Once the learner makes the correct response (achieves the criterion of mastery) he goes on to learn another step or part.

The progressive part method includes the following steps: Part 1 is learned; part 2 is mastered separately; the two are combined to form a larger part; part 3 is then learned separately; parts 1, 2, and 3 are learned as a larger part; and the procedure is repeated in progressive fashion with the addition of a part at a time in a sequence corresponding to the appearance of the parts in the whole. This procedure differs from the pure-part method in that the parts are linked in a progressive fashion as each new one is mastered rather than being connected at the very end. This could be the plan of a teaching machine program if the programer wanted to use it.

The repetitive part method sequence is: Part 1 is mastered first; parts 1 and 2 are learned together; parts 1, 2, and 3 are then practiced to mastery, etc. This additive procedure is followed until all parts have been learned. This procedure differs from the first two in that the linking of the parts is treated as a step in the learning of successive parts rather than as a separate set of associations. The first parts receive the most practice with this method.

With the whole method the learner proceeds from one part to the next, whether or not he is correct. A variation of this method is the adjusted-learning method. Applied to programing it consists of using the whole method for the first presentation of each item in the program and possibly for additional presentations, the number depending upon the criterion of mastery for an individual part which the programer decides upon. A record is kept of the correctness and incorrectness of individual items. This information is used to determine whether the student has achieved the criterion (e.g., two successive correct responses); if he has, the item is dropped out of the list and not presented again. Thus, each successive presentation is literally selected from a reduced "whole." This method is intended to insure an equal amount of learning with every item in the set and of course can only be used when it makes sense to break up the set of materials.

Research comparing these different methods has not been conclusive; consequently, it cannot provide the kind of guidance wanted. One study that does seem to take a useful approach to the problem and which might serve as a model for new research in teaching machine programs was reported by Orbison (1944).

Orbison's (1944) analysis of the problem is that the part method should become superior as the amount of material learned increases. He bases this prediction upon two functions that interact. One function is the relationship between the amount of time required to combine parts and the number of parts to be combined. As the number of parts to be combined increases the amount of time required to combine them also increases. The other function is the amount of time taken to learn additional items as lists are increased in length. He argues that some advantage in time is gained in learning longer lists, an advantage that does not increase at a rapid rate, however. In fact, while unrecognized by Orbison, it may be that this so-called advantage does not apply to very long lists (see Lyon, 1914).

As the number of parts increases, the first function of the part method operates to the disadvantage of the learner; the second, on the other hand, works to his advantage. Taking both together, Orbison concluded that at some point with respect to the length of the list, the advantage of learning a longer list would equal the added time required to combine the parts. At this point the whole and part methods would not differ from one another. Further increases in length, however, would make the part method increasingly superior.

From this it seems that with longer programs the correction procedure, or pure-part method, as built into some devices, is desirable. The programer, however, has to arrange the items so as to build repetitions or redundancy into the program in order to achieve the progressive or repetitive part methods.

Guidance and prompting

Three conditions of guidance can be identified:

1. Cue guidance—the isolation of critical cues
2. Response guidance—the deliberate elicitation of the correct response
3. Relational guidance—the presentation of the principle to be used to achieve correct performance

One of the main advantages of a teaching machine is that the critical cues are clearly identified in the program for the learner. In other words, the learner is given cue guidance. The problem statement or material preceding a blank space is the cue-stimulus. The learner's task is to make the correct response to this cue-stimulus.

Verbal directions are frequently used as response producers to narrow down the range of the learner's responses. By increasing the motivation of the learner, the rate of his responses can be increased, e.g., by pacing. The liberal but selective use of reinforcement is the method most employed to select from among those made the particular responses in accord with the criterion.

When a principle is to be used in a variety of separate contexts and each application requires a different objective response, a relational problem results, and there are at least three different relational guidance techniques that can be used in programing. Each makes the correct response more likely than when no guidance is given. For example:

1. The grouping technique—to group together a set of instances illustrating the same principle.
2. Explicit-meaning technique—to provide an explicit statement of the principle to be applied.
3. The principle and example technique—to state both the principle and instances of its application.

The early work (see McGeoch and Irion, 1952) dealt primarily with guidance in the sense of the response, e.g., mechanical guidance and manual guidance. Verbal guidance was used to tell the learners the responses to make. Benefits usually resulted, early guidance being better than guidance introduced later in practice. Cook and Kendler (1956) found that in a verbal learning task, prompts used to elicit the correct response were particularly efficient early in learning. Prompting was generally more effective than a confirmation procedure.

Giving the learner multiple-choice items instead of blanks to fill in can be considered a prompting procedure. Moreover, when the response to be given is supplied in the information accompanying a fill-in item, this information is also a prompt, since it is available while the student is making his response. The learner's task is to select one part of the previous statement that he still can see and insert it in a blank space. When used in this way, the two methods are very much alike in that both prompt the learner. The multiple-choice method forces response discrimination but limits selection. The fill-in or composition item forces response selection and requires the composition or integration of component responses but does not limit selection uniformly for all learners.

When the information required for a fill-in is in the view of the learner while he makes his response, then the construction aspect of the response is present. The learner "manufactures" the response, but he does not recall it. In many teaching machine programs using the fill-in the word required is visible in a preceding sentence. Thus the learner sees the right response (a prompt) but does not see a set of wrong possibilities as he does with the multiple-choice type of item.

With multiple choice, selective reinforcement is used to teach discrimination between the correct and incorrect alternatives. To do this most efficiently the correction method is best. In other words, the learner must make the correct response before going on to the next item. A teaching machine program using multiple choices should do two things not done in multiple-choice testing: (*a*) change the position of the alternatives from one presentation to the next; and (*b*) employ new wrong choices from one presentation to the next, to the extent that it is realistic to do so. In this way fewer choices would be required for any one item, but the learner could be led through the discriminations while keeping the probability of a correct response relatively high. Also, more incorrect responses could be eliminated with less risk.

Considering the eventual needs of the learner in using the information he is learning, these response discriminations may be very important. Use, here, does not necessarily mean ultimate use but may mean use in a mediating or transitional phase of the program. For both types of use, however, it may be desirable to teach response discriminations. When the response is to be made to several different cues, then imbedding it in one statement which provides information and asking for it in an adjacent statement that contains a blank space for it appears to be a useful technique. Each seems to serve a slightly different purpose, and a program should therefore include both, as necessary.

Craig (1953) used relational guidance in a task where a set of principles was to be learned. He found that the use of guidance as contrasted with the use of more complete discovery helped the learners avoid errors. In fact, he reported that learners made fewer errors after a single trial with maximum guidance than they did after two trials with less guidance. The amount of transfer of training increased as more and more cues were provided to aid the learner in the discovery of the principles used in making correct responses. The transfer effects of increasing the amount of guidance became greater as the difficulty of the situation was increased. The grouping of instances according to a common principle increased transfer, particularly when a short statement of the principles determining the grouping was given the learner. It is important to note that creativity (the invention of principles, correct or incorrect) did not seem to be reduced as a result of guidance.

Stacey (1949), using sixth graders in contrast to the college graduates used by Craig, did not find relational guidance more effective than designating the errors.

At least two possibilities for this discrepancy exist. Both merit further research with teaching machines. One possibility is that the particular forms of guidance interact with factors related to learners. If verified this would mean that programs should be written differently for young and for verbally sophisticated learners; that young learners should discover the correct principles by themselves and that older learners should be given whatever guidance is possible. On the surface this seems paradoxical. The other possible explanation lies in the differences in technique employed by these two investigators. Stacey used examples not represented in the actual material studied; consequently, the guidance may have thrown the learners off the track, so to speak. His instructions did not clearly indicate that the learner was to work with a set of principles different from those used in the examples; thus, there is a possibility of negative transfer.

Of particular interest was Craig's finding that the organization of the material contributed to discovery. Simply putting together in a series all instances of a single principle helped the learner. (*See* Method of agreement, p. 62.)

In different context there is evidence of the organizational factor contributing to discovery in what might be termed incidental learning. Wess (1935) used prose passages varying in length from a half-hour to an hour and studied the reproductions of children. She found evidence that their reproductions conformed to the presentation and that this conformity was capable of being increased or decreased, depending upon the structure of the material (its inherent organization). She points out the motivational importance of the presentation and stresses the need to have the material arouse the child's inquiry. Presumably this also leads to greater conformity.

The basic problem seems to be in the way guidance is used. It can be effective if used properly. Without adequate data it seems reasonable to conclude that learners of all ages benefit from all the help given them in their search for principles. It is possible that the psychological processes differ under the different conditions. When the principle is given in advance, the learner may simply memorize it in his attempts to use it. On the other hand, when the principle is not given, the individual is forced to discover it; and in being required to examine the material closely and to make inferences based upon what he sees, he may extinguish wrong responses. One procedure might be to provide explicit practice in the use of each principle. Another could be to provide explicit practice in induction. If both are effective, then it appears that guidance is not an either/or problem; both should be used.

In summary, guidance is a matter of directly making cue-stimuli salient, or of indirectly increasing the probability of the correct response. Providing the learner with a mediator achieves either or both of these things more or less efficiently. The problem in educational situations, and more specifically in programing, is that of knowing what the learner needs. If the learner errs, then the nature of the errors should be determined to obtain information useful in providing subsequent guidance. Thus the new form of guidance should be determined, at least in part, by the error behavior of the learner. The problem of guidance is not independent but rather inextricably linked to the important problem of feedback and adaptive programing. Guidance, to be maximally effective, must be thought of as a dynamic concept. It is a set of particular procedures appropriate for different learning tasks at different times in practice, and possibly for different learners. The problems of guidance are almost coextensive with the problems of programing.

CHAPTER VI

Concepts and Techniques

Some concepts and techniques for programing which are at best provisional are presented below. They are by no means complete or fully tested; the field is too new for that. Each should be considered to be a testable hypothesis which it is hoped will be examined through systematic research. They are presented here as interim guidance to the programer.

Specific Guides to the Programer

Start from the teaching objective and work back

The programer has to begin by identifying: (*a*) The specific responses that constitute criterion behavior, (*b*) the particular cue-stimuli with which these responses will become associated, and (*c*) the sequencing or organizational requirements of the task to be learned; this is the task analysis in terms of criterion behavior.

Once each task has been analyzed, it is necessary to determine, as best one can, the capability of the learner at the beginning of training. Between these two levels the transition or modification requirement is located. (See Carr, 1959.) It frequently is necessary to introduce items from outside the content area to make the transition possible or more efficient; included would be supportive items (e.g., instructions concerning instrumental behavior) and catalytic items ("verbal vehicles") for establishing and maintaining a new association. Examples are metaphors and analogies. The main point is that once the criterion behavior is identified, then the plan can be made to move the learner to that point. The strategy for this should indicate whether there is any need for items outside the content area. If additional material is needed, it is then clearly related to the strategy and not just superfluous.

Break material down into stimulus-response elements

Compile a list of the S–R pairs. For continuous discourse programs, the S–R pairs can be listed as the subject and predicate of sentences. The basic elements of the program are a set of simple sentences. The elements of a mathematics program, however, would be a set of equations, some definitions and/or operations. The elements of a program to teach a sight vocabulary would be sets of words and pictures.

After the S–R sets have been identified, their relationships to one another have to be determined. One relationship among stimuli is similarity. It implies a need for discrimination training. If, for example, the learner is simply to differentiate between two different cue-stimuli, the response can be relatively simple; however, the different responses should be maximally different, also. A simple approach-avoidance dichotomy, e.g., pressing or not pressing a button, making or not making a checkmark, is sufficient to achieve the discrimination. Some simple form of overt behavior that can be recorded is all that is required.

Not all stimulus-response connections are formed to teach the subject matter. Interspersed with content items of a program are items which serve other purposes, such as to teach cue-attention habits; for this the learner might be asked to look at an illustration to locate the position of a particular object. Items teaching cue-attention habits are often scheduled early in the program. Simple, easily discriminated parts of a complex display (e.g., a circuit diagram) may be selected so as to distribute attention to different aspects of the picture.

Keep the response simple

Simplicity of response is desirable when it can be justified educationally. In terms of engineering, simplicity of response has the advantage of making the equipment much less expensive. The response of the learner is the cue to the machine in that it determines what the machine does next. The less complex the response the easier it is to build a teaching machine to accommodate it and the easier it is to record behavior.

Complex responses are required by particular teaching objectives, and when required they should be provided for in the program and the machine. In spelling, for example, the responses must be complex, and in many other educational situations it is not possible to simplify the response.

Program information items then application items

The essential information should be presented first; then the student should be required to use the information. In other words, a program begins with something put in by the teacher which is then taken out in the form of the responses made by the learner. If the student fails to make the correct response, the program is rewritten to make the information clearer or the response simpler. The program does not start by testing the learner to see whether he already knows the right answer before giving him the information; this would be testing, not programing. The program sequence is to inform the learner, then to have him use the information. A program does not test to see whether the learner has the information and to correct him if he does not. The program is a "give and take" affair; it gives a little information at a time, then takes it back. It should not omit any step.

Identify need for association reversal

In many kinds of subject matter it is both useful and necessary to teach the learner to make associations in two different directions, e.g., English-French, French-English. Research data do not indicate that both directions of associations are equally well learned when practiced first. The extent to which each direction is learned is not necessarily the same unless there is a deliberate effort to teach the two directions to a specific level of proficiency. If in the analysis of the criterion performance it is revealed that both directions need to be learned, then association reversal has to be built into the program.

In teaching both directions of association, the programer has to decide which of the two terms to be paired is more meaningful to the learner and which is simpler. The simpler one should be programed as the response term in the direction of association taught first. Furthermore, several opportunities to practice this direction of association should be given before the direction is reversed.

Use class-descriptive features

A class-descriptive feature is an aspect of a complex stimulus which is common to two or more but not all the stimulus objects that are the occasions for different responses in the learning task; for example color, shape, position, or size may be class-descriptive features of complex materials.

In the following figures, two methods of sequencing materials are illustrated by means of two different examples. The first is the object-descriptive method of presentation. With it a total object (e.g. a dog) is presented as a whole and the different components of interest are pointed out to the learner or he is asked to describe selected components (see fig. 18). In the dog pictures, for example, the learner may be asked to identify selected features such as head, trunk, and hindquarter (or tail). Similarly, (fig. 19), in teaching the learner that a particular coin is a penny, the head (face), the tail, and the side view of the penny may all be shown so that they are associated with the coin's name, "penny". In the object-descriptive method each feature of an object is related to the name of the object, the common response. This can be described as a many-to-one relationship of components to name: many cue-stimuli for one response.

With the class-descriptive method of presentation, each of the common and significant characteristics of a set of objects is presented

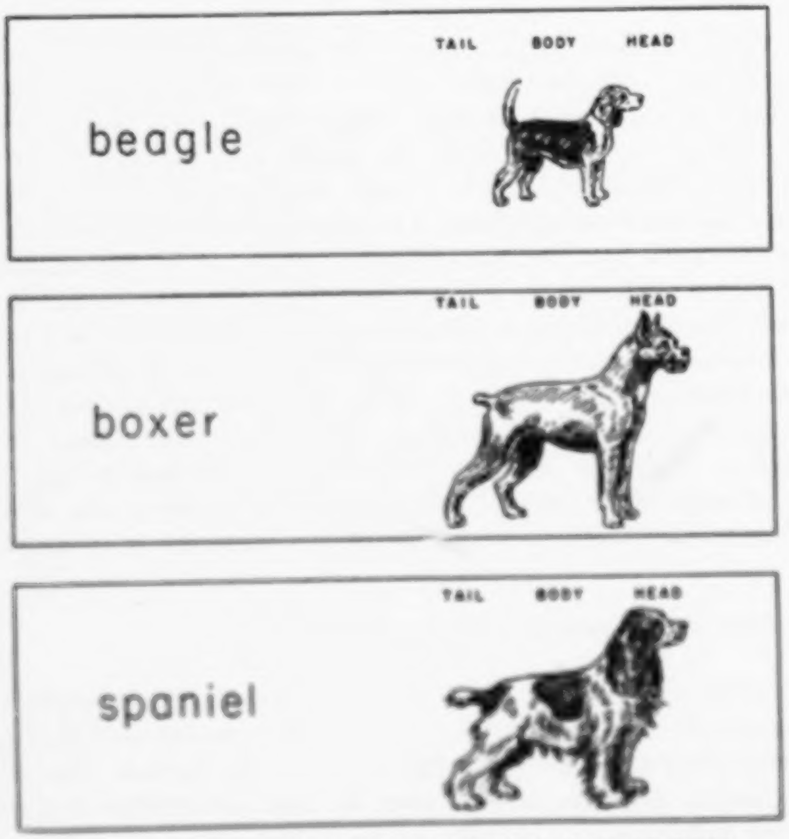

Figure 18. OBJECT-DESCRIPTIVE PRESENTATION OF DOGS

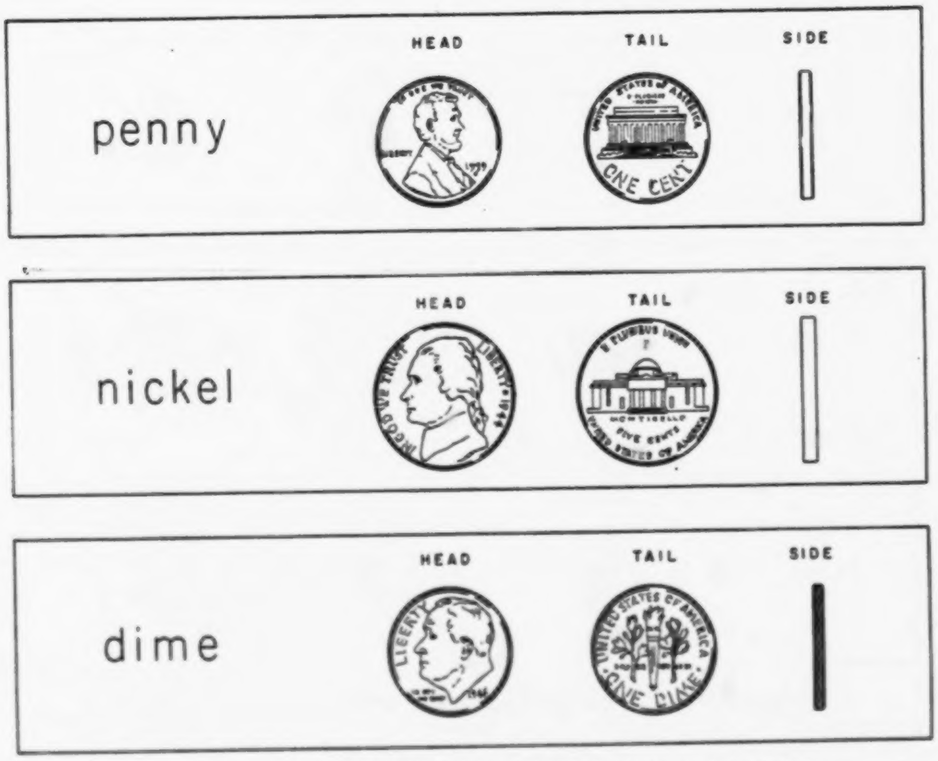

Figure 19. OBJECT-DESCRIPTIVE PRESENTATION OF COINS

to the learner, one at a time. For example, the dogs of the previous illustration might be presented as in figure 20, where the three different dog heads are presented side by side as one display, the three different trunks on another display, and finally the three different hindquarters. In the same way in figure 21, the three heads of the coin are presented together, followed by the three tails, followed by the three views of their edges—a characteristic they all have in common shown each time.

It has been shown that the class-descriptive method results in more efficient learning and better transfer to situations in which the information is used in making decisions. (Stolurow 1956; Wulff and Stolurow, 1957.)

Make cues and responses asynchronous

Consider a change in stimulus from one item in the program to the next item. For example, of two program items $X+Y=Y+$—and $R+S=S+$—note that the cue-stimuli ($X+Y=Y+$—and $R+S=S+$—) changed in all respects in going from the first to the second

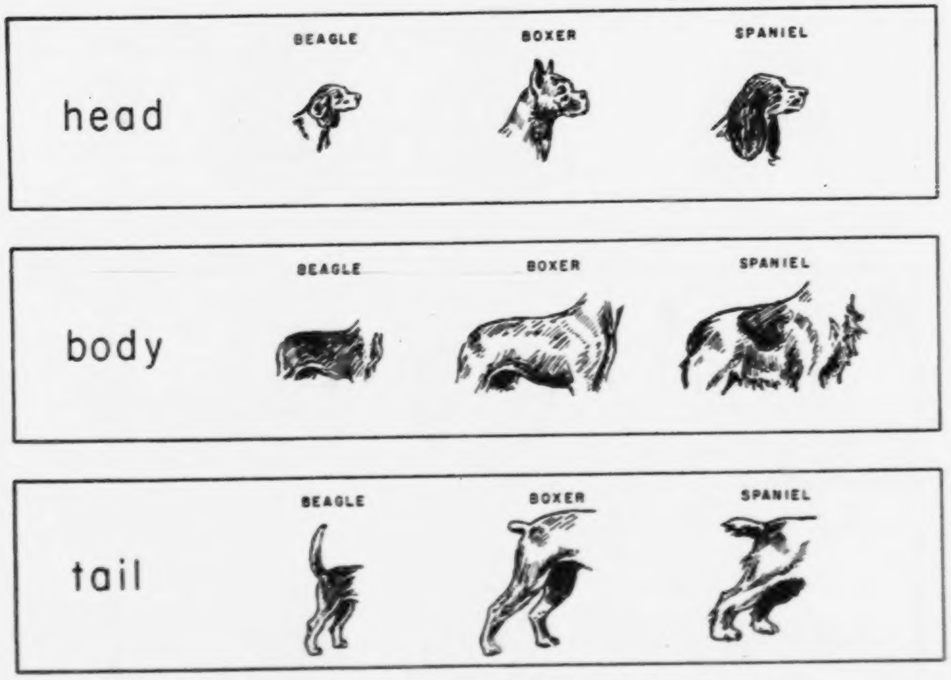
head
body
tail
BEAGLE
BOXER
SPANIEL

Figure 20. CLASS-DESCRIPTIVE PRESENTATION OF DOGS

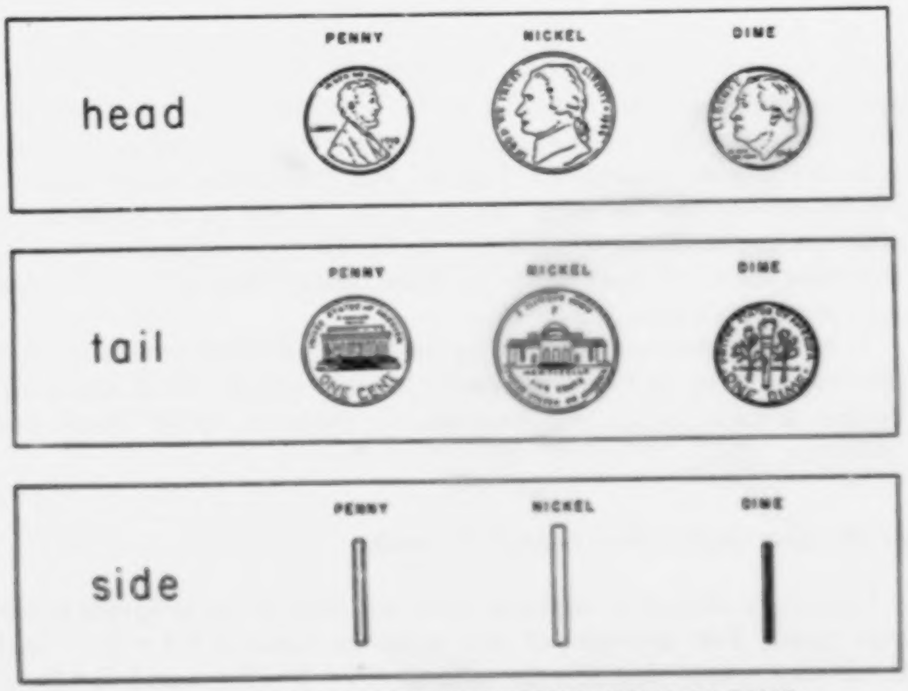
head
tail
side
PENNY
NICKEL
DIME

Figure 21. CLASS-DESCRIPTIVE PRESENTATION OF COINS

item. Now consider the response. For both of them the same mediating response, the commutative law of addition, would be appropriate, but each requires a different overt response.

In a series of arithmetic problems if a child is given a number 8 for example, and told to respond by giving two smaller numbers, the sum of which equals the number given, the number might be followed by itself four times in a row. The child would have to make four different responses, e.g., 1+7, 2+6, 3+5, 4+4.

In the example in which the commutative law was the mediating response, there was maximum change from item to item in the stimulus accompanied by no change in the mediating response. In the example requiring factoring from item to item, there was no change in the stimulus (a series of 8's) but maximum change in the response. Both illustrate the principle of asynchrony: cue-stimulus change accompanied by no change in response or no change in cue-stimulus accompanied by change in response (see Detambel and Stolurow, 1956).

Synchrony occurs in the opposite set of relationships, in which both the stimuli and the responses change from item to item in the series, or neither the stimulus nor the response changes from one item to the next; i.e., repetition.

Detambel and Stolurow (1956) found that the asynchronous sequence was associated with more rapid learning than the nonrepetitive synchronous sequence. This finding was obtained when the learners had to discover the correct response.

Craig (1953), for example, found that grouping of instances illustrating a particular principle was a particularly effective type of guidance for the learner. This procedure of grouping together instances of the same concept, or principle, (where there are obvious but superficial differences in going from one instance to the next but where the mediating response remains the same) was compared with the synchronous arrangement of the same type of material (where the learner, in going from one problem to the next, not only sees different stimulus materials but also has to make different mediating responses).

Programing according to the principle of asynchrony would place all instances of a concept together so that adjacent cues would be different in as many ways as possible. Each instance would require the same response. If the response is common to a set of items that vary in as many particulars as possible, then presumably the student is most likely to be able to transfer what he learned to other situations not included in the program. In applying the principle of asynchrony the concepts of "change" and "no change" should be related to the response that is critical and to the cues upon which it should be dependent, the relevant cues.

Build in continuity

As used in programing, this principle is sometimes referred to as the principle of "dovetailing" (Gilbert, 1958). The objective to be achieved is the explicit interlacing of associations into a pattern consistent with that required when the information concept or skill is put to use. This is accomplished by manipulating words as cue-stimuli and response producers so as to make each one function in the specific ways that build up the desired interlocking set of associative connections. For some materials a progresssive development is indicated, e.g., in teaching mathematical concepts.

If, for example, exponents are being taught, the program might begin by showing that $5 \text{ x } 5=5^2$. After several examples of the rules already described, the program would get the learner to generalize this concept by using letters instead of numbers for the base. The general expression might be programed as "If $5 \text{ x } 5=5^2$ and $7 \text{ x } 7 \text{ x } 7=7^3$, then how would you write N x N=—?". This would end part 1 of the program. This part would teach the notion that any number when multiplied by itself a particular number of times can be written as that number with the exponent representing the number of times it is multiplied by itself.

The next part of the program would lead to another generalization. It would terminate with a problem something like the following: "Any number N when multiplied by itself n times can be written as ———." The correct answer, of course, is N^n. Each of these concepts would then be combined; both would be used to teach the division of numbers which have different exponents but the same base. This part would conclude with a general expression, using as exponents two letters, e.g., m and n. However, the third part of the program would start with specific examples of a number as a base raised to a particular power. It would use as examples exponents which differed from each other by 1 or more. In this way the learner would always see positive numbers as exponents. Part 4 of the program might consist of examples in which the number is raised to the same power in both the numerator and denominator. This would introduce the zero exponent.

Repeat with variations

Repetition without variation has negative motivation properties. The same problems in addition introduced in a different context, however, are not perceived by the learner as being repetitious. Thus, repetition can be conveniently introduced by varying the context to encourage practice. Moreover, this procedure represents the use of the principle of asynchrony. When used, the irrelevant features of the problem should constitute minimal changes rather than gross rearrangements (see Silverman, 1960).

Use small steps

A teaching machine program begins with the assumption that the learner possesses the barest minimum of information that is to be taught and that the learner acquires a small amount at a time. If it is all there in small pieces, the learner can go as fast or as slow as he wants; nothing essential will be omitted. Small steps allow for the flexibility required in meeting individual differences. If the learner already knows them, he can cover them quickly; if not, he can adjust his time accordingly.

Augment the program

Augmentation is the building up of a compound or complex set of relationships by introducing one at a time in such a way that each is related to the other. To illustrate augmentation by using a set of syllogisms, item 1 in the program might be: "John is a human." "John is not a woman." "A human that is not a woman is a man." "John is a __________." From the above, the answer is either "man" or "woman". The next item might be "John will die." "John is a person." "People who die are mortal." "John is a ___________". The next item might read.: "John is a __________ __________." The answer would be "mortal man." Individual components of the total response are presented, the learner makes appropriate responses to them, and finally they are combined into one summary point.

In augmentation the objective is to build a larger response unit or concept through many small steps. The process is cumulative. The learner is given new information and required to repeat some learned responses in slightly varying relationship to the stimulus.

Build a web of association

Many associative connections are better than one. In fact, Noble (1952) and Osgood et al. (1957) define connotative meaning in such a way that it includes the multiple-association linkage. Meaning is known to affect learning and retention: more meaningful material is learned faster and retained longer.

A web of associations can be developed in many ways. One is to direct the learner to do different things with the material as in a spelling program when the learner is to construct new words from the components of the word being learned. SPACE, for example, would lend itself to such a treatment. One item might be to write the word formed by the last three letters; another to write the word formed by the last four letters; a third to point out phonic relationships; a fourth to indicate different usages and meanings. Each can serve to interrelate cues and responses useful in spelling, pronouncing, and using the word.

Gradually vanish the eliciting stimulus

"Vanishing" is the term used for the gradual withdrawal of the response producer. In using vanishing the sequence of items is designed to withdraw prompts gradually, thus making the student more and more self-reliant. To illustrate this procedure in a program in which the learner is being taught to spell the word "sheep" for example, the procedure might begin by giving the learner a picture paired with the word sheep. Then the learner might be asked to supply the missing letter when given part of the word, e.g., She——p, then to fill in the following: S——ep. The next item might require that he fill in ———ep, then S———; finally he might be given the picture and asked to write its name. The idea is to withdraw the prompts until the student is able to supply his own response.

As with augmenting, there are no precise rules to indicate how big a step to take. Experience and judgment have to be used. In general, it is probably better to err on the side of too many steps than on the side of too few; however, too many steps could make the problem trivial and uninteresting and thereby reduce motivation. Motivation loss might also come from the absence of reinforcements, the consequence of too large a step. In fact, however, it is more likely that steps will be made too large for the learner than too small. A "fine grain" program is probably better than a "coarse grain" program.

Use induction and deduction

In program writing the general question arises of whether it is better to use an inductive or deductive sequence. It appears that an inductive program is favored. In this type of program the student is given instances of a general principle and various pieces of it in the steps which terminate with the general principle (Gilbert, 1958).

There may be some merit in giving explicit examples of the application of the general principle thus arrived at. This would constitute the deductive sequence, although the process of deduction is not the intent of the programer. Rather, the purpose is to demonstrate ways in which the principle would be used.

The use of both the inductive and deductive sequences in combination is an example of association reversal, for in the inductive sequence the principle is the response, whereas in the deductive sequence the principle is the cue-stimulus. A principle is more useful to the learner if it has been presented in the program as both a response and a cue-stimulus.

Some motivational value might be achieved by breaking up the sequence into these two phases. Doing so would mean that fewer examples would be required to help the student achieve knowledge of the principle. The remaining examples would be used to teach the reverse direction of association.

Make major points salient

In teaching technical material, e.g., the functional interrelationships of a complex hydraulic system or of the vascular system of the body, it is sometimes useful to begin with an overall outline that leaves out considerable detail. This is to make salient the major components of the system and their major interrelationships. After these highlights have been taught, detail is gradually added.

The purpose is to present critical material first and to make it salient so that the student is able to master it early. However, since the information is to be used in a context in which there are many competing cue-stimuli, it is necessary to bring in details later on. Some detail is part of the main idea (e.g., circulatory system); however, some of it is to provide association with the context so as to increase transfer of the knowledge and skills learned by means of the machine. The former is critical whereas the latter, although necessary, can be accomplished by alternative means. As the critical material is introduced it should be programed so as to provide sufficient practice to produce a high level of acquisition before new material is brought in, in order to reduce the possibility of interference.

Examples of Programing Techniques

Gilbert's technique

Gilbert (1958b) identified 11 categories for use in classifying program items, namely:

1. Lead-in items—to orient the learner to a problem.
2. Augmenting items—to supply new information; instead of a relevant response they require a trivial response that insures reading or analysis.
3. Interlocking items—to add items and to provide a review.
4. Rote review items—for verbatim learning.
5. Restated review items—to provide practice variation.
6. Delayed review items—to distribute practice in a deliberate way.
7. Fading items—to wean the student.
8. Generalizing items—to summarize in general form.
9. Specifying items—to illustrate a particular rule by providing examples.
10. Dovetailing items—to integrate two separately taught items.
11. Subject-matter classification items—to introduce a class term or name.

Gilbert's intent is to provide a set of rubrics for analyzing programs. The analysis of a program usually goes on in the planning stage and in checking the data. It is done initially while the program is under construction. To do this a chart could be used in which (*a*) the rows are these 11 items; and (*b*) the columns are the items of the program in sequence. Gilbert refers to his approach to programing as "mathetics," from the word mathesis: mental discipline or learning.

Pressey's materials

Pressey envisioned materials for self-instructional devices as a supplement to the textbook, not a substitute for it. His view was that the student would read the chapter in the textbook and then take multiple choice (true or false) tests. The machine was a convenient device for the student taking the test and for the teacher scoring it. Presumably the student would later look up his wrong answer in the textbook (the pages indicated opposite the question) for additional study. Furthermore, the procedure was supplemented by group discussions. Consequently, Pressey materials placed less demand upon the programer to make the program a self-contained unit.

With this conception in mind Pressey stressed the broad or general questions that challenged the learner. He was not interested in developing an intricate and self-sufficient set of items so well cued that the learner would make practically no error. Questions that had obvious answers were trivial. Presumably the programing was in the text. It was the text that initiated the learning, not Pressey's tests, although they guided the learner. From this point of view the avoidance of error was not a problem; if a student made an error this was a sign that he had to reread the text and take the test over.

Skinner's concepts

Reinforcement is the cornerstone of programing for Skinner (1958); through it, the desired response is "shaped." The primary objective is to bring the behavior under the control of a variety of stimuli. Initially the student is lead to discuss some of the basic terms, concepts, or perceptual materials with which the program will deal later. Technical terms are slowly inserted in the material; e.g., a bell in the description of a conditioning experiment is first called a stimulus. Later on the bell is associated with the technical term: conditioned stimulus. This is done by gradually introducing items which change the set of associations. In a similar way, acid-on-the-tongue is first a "stimulus" and then it becomes the "unconditioned stimulus". Later it becomes simply the "US".

Skinner recommends "vanishing" as a technique to develop "new responses." The procedure is to evoke a particular item of behavior in the presence of an appropriate cue stimulus at least once. This permits it to be reinforced. If the programer knows what stimulus will elicit the response he wants, that stimulus is used initially but is slowly reduced as the program continues, until finally it is not used at all.

"The web of associations", for Skinner, refers to a rich associative content or understanding. This notion generates a variety of specific manipulations limited only by the programer's ingenuity. Manipulations involve both intrinsic variations of the material itself (e.g., the spelling of a word is analyzed by the student) and attachments to other related stimuli.

Skinner recommends the teaching of operations as early as possible, e.g., teaching addition and subtraction early in arithmetic. The idea would be to introduce as few elements as one needs to demonstrate an operation and then to insert new elements while introducing and using the operation. New operations are then added as sufficient elements are available. In teaching arithmetic this would mean that the program might start with $1+1=2$ and then move on to $2-1=1$. This could be followed by $1\times 1=1$ and $1\div 1=1$. Other operations would include $1-1=0$, $2\times 1=2$, etc. After these operations were taught, the program would bring in other numerals; e.g., 3 and 4.

Skinner appears to use what others might call crutches (Edwards, 1960): almost any device to make the correct response likely. This could include slang associations, rhyming, analogy, etc.; no holds are barred. *Any* stimulus is legitimate as long as it makes the correct response probable.

Concerning the programing of verbal knowledge, Skinner discusses the problem of forming written verbal responses and recommends differential reinforcement used progressively to shape the behavior. In other words, as more and more adequate forms are produced, they are reinforced, and the less adequate ones are not. The objective is to use an eliciting stimulus to produce the behavior desired.

Instruction or teaching occurs, in Skinner's opinion, when behavior is transferred to a new stimulus. One problem is to bring a verbal response under the control of a nonverbal stimulus, for instance to get the learner to respond to a picture while reading a word. Gradually either the picture or the verbal material vanishes, depending upon the teaching objective. Verbal responses can be brought under the control of a verbal stimulus by means of an "explicit defining autoclitic."[1]

Skinner recommends the use of small steps and the use of composition devices so that the learner can practice making the response which will be used in the criterion situation.

Crowder's intrinsic programing

The central concept in intrinsic programing is in the utilization of errors to build knowledge and skill. Items in the program call for a selection of an alternative in a multiple-choice set. The selection of an erroneous response leads the learner to another page in the program (or another image in a film sequence). When the learner is right, he is given additional information and a problem; when he selects a wrong alternative, he is led to information intended to eliminate the error, then referred back to the problem, where he selects another alternative. This is a branching procedure, like the use of a cul-de-sac in a maze; only in a branching program each error is interpreted to have some meaning regarding the learner's needs. The interpretation of the error is provided, with possibly some additional information, then the learner is returned to the point of choice. Straight exposition accompanied by straight or leading questions, a series of examples, a definition, problems, or analogies may be presented.

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[1] Autoclitics are operants that are involved in assertion, negation, quantification, qualification of responses, construction of sentences, and the highly complex manipulations of verbal thinking. "All these acts are to be explained in terms of behavior which is evoked by or acts upon other behavior of the speaker." Autoclitics, then, are responses to already given responses, e.g., "I recall", "I imagine", "I assume".

The number of branching alternatives does not have to be the same for all problems. No special constraints are imposed on the programer's techniques, but he does have to use a good deal of foresight. Every move of the learner has to be anticipated. The material does not have to fit a format; the basic requirements are: (a) That there be two or more choices available to the learner; and (b) that the wrong choice lead the learner to information intended to correct his error and get him back to the original choice point so that he can proceed on the right track.

Homme and Glaser's programing

These authors (1959b) propose a system known as "ruleg", which consists primarily of stating a rule or principle and giving an example. Both the rules and the accompanying examples may be stated negatively or positively. Items are either incomplete rules or incomplete examples requiring the student to respond by filling in or completing the rule or example. By using a bar or a tilde over the combinations RU (rule) or EG (example) a program can be analyzed in terms of its items so that the bar represents negative examples and the tilde means an incomplete example or rule.

Homme and Glaser have been most concerned with programing textbooks. (See ch. III.)

Barlow's programing

Barlow (1960) refers to a matrix method formulated by Homme which was originally intended to formulate program questions for the student; however, Barlow adapted it for use by the programer himself. Four terms figure in this analysis:

a. G—goal or subtheme;
b. U—unit of work to be handled at a time;
c. I—instructor or programer;
d. P—pupil or student.

A matrix is set up in which pairs of these terms represent column and row entries. A 4 x 4 matrix generates 16 questions and comments to be used. The first cell in the table represents the coincidence of I and G, the instructor's goal. This is a question to be answered by the programer. The programer uses these 16 questions to prompt himself regarding the program he is preparing.

Blyth's programing

Primarily concerned with programing materials for a course in logic, Blyth (1960a) indicates that different materials require different programing rules. The general requirement is to use the principle of proceeding from the simple to the complex, but sometimes it is necessary to depart from this "rule of thumb"; perhaps to start with a conclusion and then to identify the premise and finally the argument. Once labels have been associated with each of these components, then variations involving them are introduced. One objective of this type of manipulation is to divorce a specific statement from a specific function; in one argument the statement may be a major premise and in another it may be the conclusion. In other words, the statement is classifiable only in a context.

When context determines the critical property of a cue-stimulus as in a syllogism, it is necessary to start with the complex ("whole") rather than with the simple ("part"). Other specific devices are recommended, such as:

1. Underlining to aid discrimination
2. Making liberal use of examples
3. Preparing a controlled sequence of graduated steps
4. Beginning with something familiar to the learner
5. Using constructed answers whenever possible
6. Using small steps

Beck's programing

A teaching rule, according to Beck (1959), is a way of controlling the learner's responses, for example by copying, analogy, and deductive rules. A program is seen as a device for providing better control over the learner's responses than textbooks, lectures, and other mass media; the four critical elements in programing consist of: (*a*) The stimulus, the occasion for a response; (*b*) the response itself; (*c*) principles which guide the learner's behavior; and (*d*) reinforcement.

Porter's programing

In programing material for young children, several techniques have been utilized by Porter (1959c). The subject matter is granulated into many steps; an interlocking sequence of steps is used, in that the preceding one prompts and the hints gradually vanish. Porter recommends reinforcement that is immediate, precisely contingent, and repeatedly applied.

Holland's programing

In programing Skinner's textbook, *Science and Human Behavior*, Holland (1959a) reports the following seven principles:

1. Use of a display or panel consisting of short passages of printed material, or a graph, to which the student can refer at any time
2. Use of each new word several times in the program before the learner is required to use it as a compound response
3. Definitions preceding examples (RULEG) and both used in the same frame
4. Use of items which lead in from common knowledge
5. Use of relevant categories for response terms
6. Use of familiar, high-association frequency words or common phrases
7. Use of careful phrasing in frames to reduce the probability of undesired alternative responses.

After a program has been prepared and used, an exhaustive analysis is made of individual items to provide the critical information for program revision; thus programing is a bootstrap operation that has to be continually modified, until the error rate is extremely low.

SUMMARY

Currently program writing is more art than science. It is hoped that this will change and that research with teaching machines will provide more new knowledge about the psychology of human learning than the latter is able to contribute to programing.

This chapter reviewed some logical notions and psychological research to identify several apparently relevant and potentially useful contributions to program writing. These contributions were presented for two reasons: one, their possible value as interim guidance in preparing programs; the other, their potential value as research hypotheses. It is hoped that these implications will be put to an experimental test and that the resulting research will generate a much more substantial set of principles than can be stated now.

A review of the major contributions to programing concepts reveals some consistencies, particularly in principle, but also some differences in technique. The intrinsic or branching program takes a very different view of programing than the linear view. The implications of these positions were indicated with respect to program writing but not with respect to economics. The psychological merits, it appears, should have priority (see Klaus and Lumsdaine, 1960).

Another basic difference among programers is in their notions about the independence of their programs. Pressey feels that the teaching machine program is an accessory to a textbook or lecture. Crowder, on the other hand, considers the teaching machine program a self-contained and independent source of instruction; Skinner shares this view.

Several writers, particularly Gilbert, have recommended that the program writer make a careful accounting of his program. Gilbert provides a useful set of categories to work with, defined in terms of function.

It seems that an important first step in moving from programing as an art to programing as a science lies in the analysis of the task in terms of critical psychological elements and relationships. This of course must be done within the constraints imposed by the content or subject matter being programed. *After* this step, the next is to determine the optimum set of manipulations and techniques of presentation and control, considering first the responses critical for successful performance; when they are specified both the explicit cue-stimulus that controls each one must be specified and the to-be-established relationships between cues and responses must be mapped. The next step is to organize the program so that it is optimal psychologically within the content. Some notions about the way to do this have been described; they along with others, should be formulated as hypotheses and tested in the laboratory so that they become established as principles of programing.

CHAPTER VII

Research Findings

Much of the initial research relating to teaching machines has been designed to determine whether or not the machine and/or its program does, in fact, teach.

One result that is apparent from a survey of research is the effectiveness of teaching machines for a variety of different subjects or materials; e.g., educational psychology, general psychology, chemistry, electronics, German-English translation, trouble shooting. A second type of result is the effectiveness of the teaching machines for a variety of different groups of learners; e.g., college students, military trainees, or children (both normal and exceptional).

While there has been a history of research studies relating to automated instruction, they have only scratched the surface. Despite their number, the research studies relative to automated instruction are still limited; the resultant findings are more provocative than definitive.

A number of studies, regardless of the specific intent of the investigators, have accumulated a convincing array of evidence showing that machines are effective for teaching. Two approaches can be distinguished among the investigations. One was initiated by Prof. Sidney L. Pressey, who has been referred to as the "grandfather of the teaching machine." He and his students, working primarily at the Ohio State University, have taken an approach which is distinguishable from that taken more recently by Prof. B. F. Skinner of Harvard University and his followers.

With the Pressey approach, the teaching machine is conceived as one factor in a total instructional effort. A teaching machine is used in conjunction with the standard teaching methods, lecturing and textbook reading, to maximize the efficiency of the instruction given students. In general, the research findings have demonstrated the effectiveness of such a procedure.

Machine Component of Instruction

With respect to its effect on learning, Pressey and his students view the teaching machine primarily as an instrument for providing the learner with immediate knowledge of results about those items of the subject matter he does or does not know, after reading a text, listening to a lecture, or some combination of the two.

In the research using this approach there has been less concern with the problems of programing and sequencing than there has been with the implementation of knowledge of results, and with a "diagnostic approach" to instruction—finding the learner's errors so that a specific type of practice can be given. The resultant information can then be used by the teacher to alter the plan and/or the content of the lecture and discussion sessions; subsequent research has been concerned mainly with the implementation of knowledge of results as applied to tasks following some initial classroom experience and with determining its effectiveness in individual learning. Generally three findings emerge: (*a*) The teaching machine can produce significant increments in learning; (*b*) this beneficial effect is not limited to a particular subject matter or task; and (*c*) machine teaching is applicable to a variety of learners.

A rather thorough investigation with devices of the punchboard type was made by Pressey (1950b). His studies were completed at the Ohio State University as an integral part of a course in educational psychology given at repeated time intervals. They were aimed at showing that the teaching machine of the punchboard type produces better learning performance by providing immediate knowledge of results and beneficial effects not limited to a particular subject.

When taking the tests, the student used the punchboard and a pencil to answer questions by punching a hole in the space allotted for the alternative he thought was correct. If the pencil went all the way through, the student knew immediately that the response was correct; if it did not go all the way through, he knew that his response was wrong and could make another choice until he selected the correct response (correction procedure). Thus the objective items revealed immediately the student's correct responses and his errors. In addition to this the procedure gave the learner immediate access to the correct information by either referring him to specific pages in the readily available textbook or by discussing the error.

In one study, conducted in the second month of a semester course in educational psychology, a first group of five different student sections (totaling 149 Ohio State undergraduates) was given practice tests with the punchboard as the teaching instrument. Four 20-question practice tests were used, each one covering two chapters. On the day when one of the chapters was to be discussed the 149 students took the practice test on that unit of work using the punchboard. Afterwards their questions were answered, but discussion was not encouraged; nor was the test used in teaching. Rather, it was an adjunctive device not closely integrated into the course.

A second group of five student sections (total 132 students) took exactly the same test but without the punchboard device. These students had their paper scored and returned the next day, when a class discussion was held by the instructor, who pointed out the right answers and led a discussion of the points. With this group there was more class time devoted to discussion than there was with the punchboard groups. This group saw the test on two days—when they took it and later when they discussed it.

A third group, also consisting of five sections, covered the same material but did not use the practice test in any form.

The results showed that occasional brief tests not tied closely with the instruction brought only slight gains. Still more interesting was the finding that tests given in the ordinary way, scored after class, then returned and discussed the following day, were about as effective as the punchboard scored immediately. However, there was more class time devoted to discussion, after the ordinary tests, which may have compensated for some of the difference that might otherwise have resulted. Whereas the group not given the practice tests (third group) gained only 4 points between midterm examinations, the second group, given the tests in the usual way (no immediate knowledge of results) without the punchboard gained 10 points. A gain of 10 points also was obtained by the first group, those who used the punchboard on the practice tests. These data indicate that, either way, knowledge of results can produce more effective learning than study without it. The advantage of the punchboard is that it is a convenient and simple device for providing this knowledge immediately and without extra effort by the instructor.

In more extensive study Pressey investigated this problem again with the punchboard as the means of providing knowledge of results; however, this time the material was more carefully integrated into the course. Sections were selected by chance, and the groups were matched in terms of their status at the beginning of the course and their general ability, academic record, and grade in an earlier, prerequisite course. The course material was divided into 18 different topics; approximately 3 classroom hours were devoted to each. Six different topics scattered throughout the course were given intensive treatment with the punchboard device. For example, on the first day at the beginning of the hour, the students took a 30-item practice test and then looked up any doubtful questions and discussed them with other students and the instructor. On the second day assigned to a topic, another practice test was given near the end of the hour, with further discussion. On the day after the topic was finished a 30-item check test was given in which 10 questions were repeated from an earlier test, 10 were paraphrased, and 10 were new. This test was given on the day of a new unit not treated this way.

These "check tests" showed that the punchboard group performed significantly better than the group not given practice of the kind described. This was true for all three types of questions. The largest differences were found for repeated paraphrased questions. Since significant differences were found for the "new items" this was interpreted as an indication that the punchboard led to better understanding of the topic as a whole. The results also showed that the punchboard group performed better significantly on the "midterm-plus-final" examination. The difference was significant at the 1 percent level. The study showed clearly that immediate knowledge of results, as provided by the punchboard device, can produce significant gains in learning.

In still another study, Pressey studied the value of frequent, brief tests. He compared the following three groups: (*a*) A group of 132 students divided into 4 sections taking practice tests with the punchboard and thus receiving immediate knowledge or results; (*b*) a group of 70 students taking practice tests as regular examinations without the punchboard but with discussion allowed after completion of the tests; and (*c*) a group of 225 students using neither the punchboard nor the practice tests.

Pressey's research and that of his students led him to four conclusions. First the punchboard is a simple way to facilitate learning by combining test-taking, scoring, and immediate feedback. Second, the punchboard is a useful and effective means for transforming test-taking into a systematically directed self-instruction program. Third, the punchboard when used systematically and integrated into the course to provide self-instruction produces gains that are substantial and sufficiently generalized to justify the assertion that the students' understanding of the subject-matter is improved. Fourth, the punchboard is one of a variety of means by which automatic scoring and self-instruction can be achieved.

A fifth conclusion also seems warranted although it was not explicitly made by Pressey; namely, that providing individual learners with immediate knowledge of results through the punchboard can be applied successfully to a variety of different subjects. This conclusion is based upon results from such diverse materials as nonsense syllables, foreign vocabularies, glossaries of naval terms, naval R.O.T.C. training material, and educational psychology courses.

Other investigators also have found that knowledge of results is an important factor in learning in higher education.

Little (1934), in what was probably the first report of systematic use of teaching machines in a regular university class, used two different Pressey machines to present items in educational psychology. The control and experimental groups were paired on the basis of intelligence and a pretest on the subject matter. In Little's view the study demonstrated the feasibility of these aids for adults studying educational psychology. One device used, the Pressey multiple choice or drill machine (1926), included a mechanism for controlling the program so that the individual had to make the right response before the next item appeared (the correction procedure or pure-part method). The other device, a rapid, automatic test-scoring machine, allowed the instructor to give objective examinations and have the scores ready during the class period. This device permitted the instructor to determine the questions most often missed so that he could conduct class discussions of the items.

Little refers to these as the "test machine" and the "drill machine", respectively, and reports that both the "test machine" group and the "drill machine" group performed better than the control group. This result was determined by a 200-item multiple choice test which revealed a difference between the medians of the experimental group and their controls. A difference of 9 points and a probable error of the difference of 1.92 was found in favor of the test machine group. The ratio of this difference by its probability error was 4.69. For the "drill machine" group the difference between medians and their controls was 17 points. Here the probability error of the difference was 2.34, and the ratio was 7.26. Both are statistically significant differences.

Angell and Troyer (1948) used the punchboard device in teaching college chemistry. They report, "* * * data from both studies showed that learning is significantly enhanced by immediate knowledge of results through the punchboard technique" (p. 93). Angell (1949) in another study used the punchboard device with three hour-long quizzes, each taken by 41 matched pairs of freshman college chemistry students. These students were given a variety of problems to study, and after practicing they took a test used to evaluate the effectiveness of the procedure. The results indicated that the experimental group of learners performed slightly better on application problems than on factual problems; however, the difference was not significant. These findings in Angell's view demonstrate the importance of the technique, whose effectiveness rests on the efficient feedback it provides each student.

Viola Cassidy (1948), working with Pressey, conducted a series of studies on the effectiveness of the punchboard. The students in the experimental group devoted about one-third of the class time to the use, scoring, and discussion of the punchboard tests. The students in the control group devoted all of their class time to the discussion of the same topics. Again the results show clearly that immediate knowledge of results as provided by the punchboard device can produce significant increments in learning.

Briggs (1949), who also worked with Pressey, used the punchboard device in studies of accelerated training for superior students at the Ohio State University. In each of four school quarters Briggs selected 30 students out of a class of 300 to participate in accelerated seminars in which they were tested on factual items and the application of concepts using the punchboard. Laboratory demonstrations and discussions of supplementary material were used along with the punchboard to promote instruction. During each quarter the accelerated students took the same midterm and final examinations as those in the regular course (the control groups). The students in the accelerated program, who were paired with those in the control group on the basis of intelligence and other factors, were able to achieve higher grade scores in the course than the controls. Briggs found that 65 percent of the experimental group earned *A* and *B* grades; only 35 percent of the controls earned such grades. The test scores also were used as a dependent variable, and through analysis of variance Briggs found a superiority for the accelerated group over the control which was significant at the 5 percent level.

In an effort to determine specifically the effectiveness of knowledge-of-results as a factor in the promotion of learning, Briggs compared two different methods—the correction procedure and the noncorrection procedure—and found that both methods were superior to the use of the test alone. This study not only indicates that knowledge of results plays a significant role in the use of the punchboard but it also corroborates the results from the previously mentioned investigations. Furthermore, it extends those results by pointing out different ways of achieving effective learning. For both procedures the t-test revealed significance at the 1-percent level of confidence.

Jensen (1949) also used superior, highly motivated students (N=24) at the Ohio State University. He, too, found that they earned better grades in the course after guided independent study through the use of the punchboard than did students who attended the regular courses. The punchboard was used in this study with the correction (part) method: the student had to make a right response before proceeding to the next item (correction procedure). Jensen found that 34 percent of the 24 students in the study earned *A* grades as contrasted with 10 percent in the control sample who were matched with them.

Collectively, these results with the punchboard clearly indicate that even with adult, sophisticated college students a simple strategy of providing immediate knowledge of results contributes significantly to the rate at which they learn. When knowledge of results is provided by the punchboard device in a casual manner, however, the effect is small and difficult to demonstrate. On the other hand, when there is a deliberate effort to integrate the use of knowledge of results into a course in a systematic manner and to provide it fairly frequently, then learning seems to show the cumulative effect of the variable in a statistically significant manner.

Further evidence of the need to integrate reinforced practice into the instruction comes from Freeman (1959) who conducted two studies using an electrified version of the Pressey punchboard and stylus device. A pen-light stylus was used and so designed that when the learner inserted it into the correct hole, the light on the stylus lit up to indicate that the response was correct. This made it easy for the examiner to know whether the learner was right or not, so that he could readily tabulate the total number of responses required by the learner to get a correct response for a particular item.

This device was used with introductory psychology students. The experimental group took two 50-item examinations, approximately four weeks apart. Their performance on the final examination after using this version of the punchboard was analyzed, using 2-part scores: (*a*) Items from the course during which no reinforcement had been given, and (*b*) items relevant to earlier, specifically reinforced examinations. Freeman found no effect relatable to reinforcement. He offers three plausible explanations for this. The first was that there was an insufficient amount of reinforced practice (only 2 examinations of 50 items each.) Second, the final examination items were not identical with the earlier reinforced items, therefore the transfer effect may have been insufficient to measure. Third, there was very little attempt to systematically program the reinforced test material.

These negative results corroborate Pressey's early findings and indicate that under conditions typical of classroom testing the casual and unsystematic use of reinforcement procedures probably has little effect on retention. Furthermore, Freeman used two long quizzes instead of following Pressey's recommendation of using frequent short ones.

Another issue also emerges from this study; namely, the fact that rapid gains in learning may not mean better retention also. This potentially important finding has been reported in some laboratory investigations of human learning (see Underwood, 1959a). Freeman's study therefore indicates the need for systematic information concerning this basic relationship between the efficiency of teaching machine programs, as judged by error rate, and the resulting retention.

In another set of two studies using relatively small, homogeneous groups of advanced general psychology students (N = 12 to 16) evidence in favor of reinforcement was obtained (Freeman, 1959). Although his first study showed no significant differences, some were found which favored the items reinforced. In the second study a significant difference was obtained; the same test was readministered without reinforcement and the groups were compared in a test-retest interval of two days. The overall performance of the experimental group was significantly better than the control group; the experimental students were not only better on the original test but also maintained their superiority on the retest.

In a replication of the second study this finding was not supported; however, an interaction between gains (test-retest differences) and learning conditions was significant. In the replication the average of the experimental group was a gain of about 20 times that of the average for the controls (3 versus 0.15 points).

Freeman concludes that the effectiveness of knowledge of results may depend upon the degree to which the programing of the material is systematic. He also suggests that the type of test used to determine retention may affect the results obtained, and that the amount of reinforced practice may be a third contributor. Which of these is the most important is difficult to say. Certainly each merits further study. We do know that practice effects from repetition of meaningful prose materials reach an asymptote after just a few (e.g., three or four) trials, so that a larger amount of repetition is not likely to give much of an increase in effect over two or three trials.

In another study dealing with a course in educational psychology at the Ohio State University, Stephens (1953) compared an experimental group who used the Drum Tutor (Pressey's device) to obtain immediate knowledge of results with a control group who used no device. Differences were found in favor of the experimental group.

Since other sections used the punchboard instead of the Drum Tutor it was possible for Stephens to make an additional comparison between the groups using the punchboard and the Drum Tutor. This comparison was made with a group who used the punchboard on only one trial but who used the same practice test. Stephens reports that on the overall examination the group who used the Drum Tutor performed about as well as those who used the punchboard and that on items which were repeated from the practice test those who used the Drum Tutor performed better than those who used the punchboard. A comparison was made of the effects produced by immediate knowledge of results provided early in learning (with the Drum Tutor) with immediate knowledge of results provided after learning under other conditions (with the punchboard). These data suggest that when testing for retention it might be better to provide immediate knowledge of results early in the learning process than to provide it after more learning has taken place.

This possible difference in the use of knowledge of results should be systematically studied in view of its implications. It agrees with the findings of earlier investigations on the use of guidance in practice; namely, that it is more effective if given early. If, for example, reinforcing each step of original learning was found to be more effective in a test of retention than providing immediate knowledge of results after some learning had taken place, this would argue forcefully for the extensive development of complex teaching machines and programs. On the other hand, if an equivalent or superior level of performance was found to result from the use of immediate knowledge of results with a testing device employed sometime after learning had been achieved by more conventional means, then a still more economical means of increasing the effectiveness of instruction would have been demonstrated. Furthermore, extensive programing would not seem to be required.

A third approach to be studied is the combined use of these two procedures. In such an approach one group would be taught by a machine providing immediate knowledge of results during each step and also after learning had taken place (use of a multiple-choice retention *test* with immediate knowledge of results). With this dual procedure, knowledge of results could operate both during learning and during retention testing. Stephens' data suggest that a group given this type of instruction would perform significantly better than either a control group or groups given knowledge of results only during learning, or only during a retention test, assuming results are additive.

This distinction has implications related to the Pressey-Skinner differences in approach that transcend this study. With Pressey's approach it is more likely that the immediate knowledge of results is provided later, since the device is used along with a regular instructional program. Skinner's approach, using the machine to do all of the instruction, would provide immediate knowledge of results early in learning rather than later on.

The data obtained using the Pressey approach in college classes clearly indicate the importance of knowledge of results for the production of superior performance on verbal learning tasks. These studies argue for its use late in learning, during the testing of information retained from prior learning. There is little doubt that the procedures employed are effective in producing higher levels of performance when used in a consistent and integrated manner than when used only casually. Casual and occasional use, without systematic integration, appears to be worthless. In general, it seems that when students are taught by any means and are tested to determine the amount learned, they will tend to perform better at a later time if during the first test they are given both immediate knowledge of results and the correction (or pure-part) method of training, or guidance regarding the correction of their errors.

A related set of studies, somewhat less extensive than those already reported, also used the Pressey approach to determine the implications of immediate knowledge of results. Here, however, the learners and the subject matter were different from those of the studies described. In these investigations military trainees were taught technical subjects.

Briggs and Besnard (1956), for example, reported a study in which a teaching machine, the Subject-Matter Trainer (SMT—See table 2), was used to provide immediate knowledge of results. This is a study of the differences in performance that might be achieved through greater or lesser amounts of reinforced practice. The SMT was used in 16 out of a total of 114 hours of instruction for the experimental group, and in only 14 hours of instruction for the control group. The students, all Air Force trainees, were matched on relevant aptitude scores and were given training on a portion of a maintenance course covering an aircraft fire control system. The written criterion test which provided the scores used in the comparison consisted of 162 multiple-choice items dealing with knowledge of circuitry and functioning of the fire control system. For the experimental group the subject-matter trainer provided reinforced practice in learning facts and principles and the preliminary rehearsal of maintenance procedures. The "practice mode" was used; this is the correction method or the pure-part method. The learner selects an alternative, indicates this with an overt response, and is told immediately whether or not he is correct. If he is correct, he sees a green light; if incorrect, he sees a red light and must make another choice until he selects the correct one. In this device there are 20 possible alternatives from which he can select for each question.

On the performance tests given individually to all the trainees, the experimental group, having received three types of reinforced practice—the SMT, study guides, and instructor administered informal oral and written quizzes, scored higher than the control group, who did not use the SMT but did use the study guide and quizzes.

The performance task required the trainees to carry out six check-and-adjustment procedures on a device that simulated the real equipment. The experimental group scored higher than the control group on the performance test; however, the groups did not differ significantly on the written tests. These data are somewhat puzzling in that the reinforced verbal training provided by the SMT did not show up on the verbal written test but was revealed in the performance task. The data suggest that the verbal learning accomplished by the use of the SMT provided additional useful mediators for performance but not for the written test.

This finding is certainly an important one, particularly for industrial and military training, where some type of performance is required as the criterion task. The question of how transfer is mediated from verbal practice to overt performance needs intensive re-examination. Since several aptitude levels were employed and the results were about the same for all of them, it suggests that the difference is not limited to a particular ability level. Without aptitude data it might have been inferred that higher ability groups make the translation from verbal learning to overt performance, but that lower ability groups do not. This, however, does not appear to be the case.

Bryan and Schuster (1959) had 113 Navy electronics technician students at Treasure Island, California, study troubleshooting principles for the DAS-3 Loran, an electronic navigational aid. Each student participated in the experiment for five days. On the first day standardized formal training was lecture-presentation by means of tape and slide, question periods, and familiarization with the training material. This was followed by three more days of conventional training. Five different groups of students were employed; the detailed training conditions will be discussed in a later section on guidance. Group 3 used the Optimal Sequence Trainer (OST), another means of providing immediate knowledge of results following specific response.

The independent variables were (*a*) degree of guidance, and (*b*) amount of explanation given. The dependent variable was a score on an objective trouble-shooting test. Results from the test show that the performance of the two guidance groups was significantly superior to the no-guidance group ($p<0.05$). This was true for both the number of items correct and the total number of tabs pulled. The groups given explanations were significantly superior ($p<0.01$) to the others in the total number of correct items. Elapsed time differences were insignificant.

Cantor and Brown (1956) investigated the influence of various training methods in teaching electronics troubleshooting. Three groups of U.S. Navy trainees were used. The first group was a T-T

(Trainer-Tester) group; the second was a P-T (Punchboard Tutor) group; the third was an E (Equipment Only) group. The "Trainer-Tester" (see table I) is a large sheet with silver overlay printed on top of answers to troubleshooting problems. It is a device originally developed by van Valkenburgh, Nooger, and Neville on the basis of earlier development accomplished at the Special Devices Center of the Navy. The Punchboard Tutor was the device developed by Pressey. The Equipment-Only group used the Navy's traditional method of instruction in electronics, involving actual mockups of the electronic equipment.

Cantor and Brown report that the absolute differences among the groups were small for the overall measure. The T-T and P-T trainees obtained higher mean achievement scores than the E group. These differences were all statistically significant with one exception; namely, that the P-T group was not reliably superior to the E group in overall troubleshooting grades. There were no significant differences between the T-T group and the P-T group.

Cantor and Brown (1956) examined further the possible extended effects of the specialized differential training by looking at the advanced training scores of their groups. The differential training had been given in the basic electronics course. However, no significant differences were found among the three groups in any of the measures. In their opinion the results support the notion that troubleshooting exercises in the laboratory could be replaced, in part, by classroom practice with such synthetic training aids for troubleshooting as the ones they used. To some extent this conclusion came from the fact that the difference between the groups was found not only in the basic electronics course but also in radar laboratory grades.

The fact that the specially trained groups performed better on written examinations than the equipment-only group suggests that there was something very different in the training of these subjects as compared with another group studied by Briggs and Besnard (1956). In the Briggs and Besnard study the reinforced practice by a teaching machine was shown to benefit the performance measures but not the written tests. In fact, in the higher aptitude group the controls obtained higher written test scores than did the experimental group trainees. In the Cantor and Brown studies, differences were obtained with the written examinations. Cantor and Brown point out that their learners received additional practice on the answering of multiple-choice questions in troubleshooting; consequently, it would be possible for the effect of the differential training to be revealed in the written examinations, but this also was possible in the Briggs and Besnard study. The fact that Cantor and Brown found the effects of teaching-machine instruction showing up in the students' laboratory grades suggests that in their study, performance also benefited by this special training. This direction of transfer effect corroborates the above finding reported by Briggs and Bernard concerning reinforced practice.

The laboratory grades in the Cantor and Brown study cannot be regarded as uncomplicated indices of manipulative proficiency in the laboratory, however. Since they were to some extent based on short quizzes, it appears that the differential training effects were expressed through verbalized training and its relationship to the verbal laboratory tests, or verbal-verbal transfer more than verbal-motor. While the latter type of transfer seems to be possible, according to the results of stimulus predifferentiation studies in which the verbal response practiced on the first task is symbolic of the overt motor response made to the stimuli of the second task, it does not seem to have taken place in this study.

These two studies, from opposite points of view with respect to the relationship of verbal training and performance or motor training, relate to the same basic problem: the extent to which the training provided by a teaching machine generalizes or transfers. This will be discussed later; meanwhile, two points can be made here. One is that in the Briggs and Bernard study the training was given with respect to perceptual and motor skills, and the results did not show transfer to the verbal symbolic test. The other is that in the Cantor and Brown study the reverse was the case. The training was given on the verbal skills and did not seem to be revealed clearly in performance differences. Together these data suggest that teaching machine practice in technical areas must be deliberately planned to cover both aspects of the job and not just one of them: both verbal skills and motor skills. Either the verbal training is deliberately planned to relate to overt motor performance or it is not. If it is directly related, it *may* transfer; but if it is not, the data indicate that it probably will *not* transfer to motor performance.

With respect to the basic question of the effectiveness of the teaching machine, the studies taken together indicate that teaching machines can be effective both for teaching verbal, symbolic skills which mediate performance and for teaching overt manipulative performance.

Also in the Pressey tradition (using a teaching machine as an added component of an overall training program), Mayer and Westfield (1958) employed the Subject-Matter Trainer (practice mode) as an on-the-job proficiency-maintaining device in the New York Air Defense Sector of the SAGE (Semiautomatic Ground Environment) System. Both interceptor directors and track monitors were trained in knowledge of components critical to the development and maintenance of operator proficiency on this equipment. An alternative group studied by means of a workbook which consisted of a set of the same 20 questions relating to the interpretation of coded material on a map. On the back of each question page (on the outer margin) were the answers (knowledge of results conveniently available) and if the student wished to look ahead among the answers listed there, he could prompt himself for the next question. The time available for training was controlled; however, the machine had built-in time delays, whereas with the book the trainee could adjust his time to suit himself.

Mayer and Westfield found that both groups made gains, and that some of the gains favored the workbook group. Since no control group was employed—all received immediate knowledge of results but differed in the method by which this was achieved—the data suggest that a printed format may be at least as effective and possibly even more effective than the Subject-Matter Trainer. A useful hypothesis is that a simple printed workbook of the programed textbook type or the scrambled-book type might be even more effective as a method of maintaining proficiency of sophisticated learners than the Subject-Matter Trainer, an expensive electromechanical device. It is obviously necessary to make additional comparisons to determine whether this hypothesis is correct; however, these preliminary results suggests that it is worth further study.

The motivating properties sometimes attributed to hardware devices may be less important in the context of learning on the job than in learning in an academic setting or in children's learning. While the Mayer and Westfield data are consistent with this interpretation, they are insufficient to establish the point. Comparative studies with children seem to be necessary. They should be controlled for other factors than just time allowed for study, and in some studies the time required to achieve an errorless performance during learning should be determined. In this case study time would be a dependent variable.

In summary, the research results with adult learners (college students and military trainees) using teaching devices in connection with other methods of instruction show a fairly consistent pattern. Generally, these devices are associated with rapid learning. In a wide variety of contexts, with several different kinds of subject matter, and with adults of varying levels of ability, it appears that knowledge of results, if implemented in a fairly consistent and systematic manner, is likely to have important educational and training benefits. Furthermore, the results seem to justify the cost. This does not mean that the most economical and efficient method should not be sought.

To the contrary, if the printed materials are cheaper and more efficient than hardware they should be used.

This brief review of selected studies indicates that teaching machines can produce significant effects with adults when used in the context of a course. However, since several possible methods of use exist and the optimum ones have not been identified, much more research is needed on the specific methods of using teaching machines as a component of an instructional program. When a machine is used along with other means of instruction, certain problems arise that might be clarified by research in which a machine is used as a sole source of instruction. Eventually it will be important to know how the devices that are effective when used alone work in conjunction with other types of instruction.

Some hypothetical possibilities might clarify this point. For convenience the contribution of the teaching machine to the learning process can be designated as the TM (teaching machine) effect, and the contribution of other instructional methods as the OIM (other instructional methods) effect. Several results are possible if machines comprise one component of the total instruction; for example, the TM effect can add to the OIM effect to produce a somewhat larger overall effect. Another possibility is that the TM effect multiplies the OIM effect to produce something more than just an additive increment. A subtractive possibility also could exist, even though it does not seem likely. Furthermore, the negative effect also could be multiplicative. The early study reported by Pressey, Freeman's study, and the study by Cantor and Brown might have obtained marked positive effects with the teaching machine as the only method of instruction. A suppression of the machine's effect may have been produced by the other factors contributing to the students' instruction. The following studies deal with the contribution of the teaching machine when it has been used as the sole source of instruction.

MACHINE AS SOLE SOURCE OF INSTRUCTION

Many studies have employed a teaching machine as a sole source of instruction; they reveal the contribution of the teaching machine independent of the effect of other instruction.

Studies with normal children

Sonia Osler (1960) has described a device now sold commercially by Foringer which automatically presents two stimuli simultaneously and dispenses a primary or token reward for each correct choice. A filmstrip is used, and the images are projected on a display panel below which are two telegraph keys for response. A white spot on the filmstrip controls the program, which can be as long as 130 35 mm. frames. A variety of material can be displayed: For example, each frame could contain a pattern, and the program could be designed for reading readiness training; also, word-and-picture sets could be programed to teach sight vocabulary.

Osler used children from age 6 to 14 to teach concepts and obtained a mean time for 130 trials of only 15 minutes. Manual methods had required 65 minutes to teach the same concepts. This device appears to have advantages over a live teacher or teacher's aid in the time saved. Further research seems necessary to determine optimum conditions for use of the device in providing reading readiness instruction, teaching sight vocabulary or arithmetic operations, etc.

Douglas Porter (1959), working at the Harvard University Laboratory for Research in Instruction, reports the results obtained in spelling instruction with teaching machine methods. He has taught elementary school children who used a simple mechanical device while working at their desks in class during a school year. The device used was the Porter machine (see table 7). The program for the teaching device encompassed the standard lessons used by the control groups and required by the school in which the children were enrolled. The same words were taught and covered identically; sentence content and reading difficulty were also matched for the two groups. The children were in the second and the sixth grades and were given 22 out of the normal 34 weeks of spelling instruction by means of the machine. The experimental groups were compared with a control group taught in a more conventional manner.

As programed, the materials required the learner to do the following things:

1. Identify the spelling words in a meaningful sentence context;
2. Match the correct word with given definitions;
3. Match several words on the basis of letter structures; and
4. Write missing letters in words presented in a sentence context.

No spoken instruction was given to the children. Furthermore, the device through its means of presentation restricted the learner to a single segment (item) of the material at a time.

For both the second and sixth grades the spelling achievement as measured by standardized achievement tests was significantly superior for the experimental groups. Observations of the sixth graders indicated that the experimental groups spent about one-fourth as much time in studying spelling as the control group. With the second grade students high rates of responding were observed. Porter reports that there was a spread of nine lessons between the experimental and control groups after a 12-week period during which the machines and the material were available on an *ad libitum* basis. At least two factors could contribute to the rapid response rates: (*a*) Release of the better students from the usual response constraints, and (*b*) the motivation (reinforcement) effects of the machine and/or program.

At the second-grade level the grade equivalent scores on the standard achievement test covering the year's work showed that the experimental group achieved a mean of 0.80, whereas the controls achieved a mean of 1.10 (significant at the 0.05 level). The letter-position scores, however, showed that the experimental group mean was 65.8, whereas the control group mean was 37.8 (significant at 0.001 level by the Mann-Whitney U-Test).

At the sixth-grade level the mean student achievement score over the year in "grade equivalent" scores showed the experimental group at 1.42 and the controls 0.30 (significant by sign test at the 0.01 level). No letter-position scores were reported. However, Porter does report that the "time at study" ratio of experimentals to controls was 1 to 3. In other words, the children with the machines mastered the subject matter in less than one-third the usual time. Also reported for the sixth graders was the lack of difference between the first and second half of machine-taught lessons. This suggests that the "novelty" effect, if any, did not wear off in the course of the year. In fact, more students said they preferred spelling instruction by machine than by teacher.

The data show that the children who used this teaching machine and program benefited in their mastery of spelling. From an examination of the operations required of the students, it appears that at least four procedures might have produced the observed effects:

1. Explicit instruction to the student to underline particular words in a sentence.
2. Circling rhyming words.
3. Circling a word of the same meaning, a synonym, (possibly involving mediated generalization).
4. Filling in missing letters (drawing the child's attention to specific details of the word's letter pattern).

Each of these procedures could be manipulated independently and in other combinations to reveal more clearly what is their individual and joint contribution, if any.

Porter (1960) in another study employed a novel procedure to isolate the contribution of context (semantics and syntax) from that provided by phonics in teaching reading. He adapted a method first reported by Ebbinghaus and later used by Taylor (1956), who called it the "cloze" procedure. It consists of deleting significant words from a text read by the student. This removes all "sight" cues that would normally be present in teaching *new* words. Data were reported on 28 third-grade students using forth-grade exercises appropriate to their reading level. Two different dependent variables were reported: (*a*) Percent of exact missing words correctly guessed; and (*b*) percent of synonyms or other words inserted to make sense of the sentence.

Porter found that 23 percent of the guesses were exact and for individual blanks the percentages varied in difficulty from 0 to 100 percent. The other measure revealed that 82 percent of all guesses made sense consistent with that of the original word. With this measure the difficulty range varied from 40 to 100 percent. Further checks showed that the substantive meaning of the partly deleted story was attained by the experimental subjects. They knew what they read as well as the controls who read a complete version.

Porter's opinion is that these figures probably underestimate the importance of phonic cues for first-grade materials written to provide large amounts of specific word redundancy and overestimate the importance of phonics for adult reading materials. A second factor mentioned is that of the reliability of phonic cues due to irregular spellings of specific sounds.

The semantic and syntactical cues revealed by Porter's procedure of item analysis—based upon differences in percent correct for the items imbedded in distinguishably different contexts—are susceptible to more systematic use to determine the variables underlying the development of verbal skills. Some indication of the procedures for optimum programing could be revealed by using rules for deletion of words, and in this way the nature of the weak semantic and syntactical links in language could be identified. Stolurow and Newman's (1959) analysis of the intercorrelations of objective indices of readability (Gray and Leary data) provide some explicit guidance in selecting the words to be deleted.

Taylor's reported relationship between his technique and "standard" readability indices suggest that for adults two factors would contribute to a high percentage of exact fill-ins: use of common words and simple syntax.

Meyer (1959a) used a machine designed by IBM to teach arithmetic and spelling to children of varying age and scholastic ability. Initially the work was designed to indicate difficulties that might emerge in the mechanics of using the machine. Children varied in age and scholastic ability. The behavior assumed to be available was: (*a*) the ability to match a letter, or number, with its equivalent on the answer slider; (*b*) interpretation of pictures representing objects and actions; and (*c*) minimal reading vocabulary.

The arithmetic course began with three numerals (0, 1, 2) and the "concept" of addition as: (*a*) process of putting groups together and (*b*) steps up a number series. Later each new numeral (single digit) was introduced as one more than the one just presented. Then the numeral 3 was introduced. Grouping was introduced for all numbers up to 9 by the time the numeral 9 was introduced.

The behavior assumed to be available was the level of discrimination required in matching a letter or a number with its equivalent, interpretation of pictures representing objects and actions, and a minimal reading vocabulary, three- and four-letter words.

The reported results are scant. However, a few hypotheses are suggested. One is that Thorndike was correct in summarizing his research regarding the specificity of particular associative connections; e.g., learning $1+2=3$ does not also mean that the child has learned $3=1+2$. In more general terms, learning an A–B direction of association does not also mean that the B–A direction has been learned. Nor does it mean that other permutations have been learned if the cue stimulus and/or response happen to be complex, e.g., $4+1=$—. Each cue-response appears to be a separate association that requires some practice of its own, at least until a sufficient (but unknown) number have been formed to provide the learner with a basis for "manufacturing" other responses on his own. For example, errors of the kind $2=1+3$ were common with fourth graders after having learned $1+1=2, 2=1+1, 1+1=1+1$, etc., with all the numerals of 9 and less. This type of error suggests that the simple operation of spatial rearrangement of the number signs is learned before the arithmetic operations. Definitive data on this point would be useful.

Miss Meyer also made an observation that was contrary to the usually accepted notion of arithmetic teachers, to the effect that there are only 100 or so "facts" with answers of less than 10; her experience was that the children had to learn *more than* 2,000 such facts with her program. This probably is a phenomenon which most programers will discover with surprise; in other words, a subject consists of many more units or items of information than ordinarily realized. Our concept of the number of different cue-stimuli to which the learner must make a response is probably going to be greatly enlarged in the near future. This finding has an implication of interest educationally; namely, that the difficulty experienced by students in learning from a textbook, lecture, or film is to some extent related to the eliptical manner in which the cue-stimulus material is presented. The teacher, as a subject-matter expert, can skip inadvertantly over many "small" points which need to be filled in for the novice. Furthermore, different learners need to be filled in on different points, so that a program designed to be used widely, even though for a single learner at a time, must contain a much larger number of steps than current textbooks would indicate. The informal comments of many programers confirm this. Blyth and Holland for example, have reported that in their experience it has been necessary to modify programs by granulating big steps into smaller ones.

Miss Meyer (1959) in another study (unpublished) used a programed textbook containing 19 lessons—seven introductory and 12 teaching 26 common prefixes—to teach 58 students in 3 eighth-grade classes. The variables studied were (*a*) immediate vs. delayed knowledge of results, and (*b*) whole method correction procedure (". . . return to wrongly answered items"). The students were given a pretest and a posttest, both of which had three parts. Part I required identification and definition of each of 26 prefixes presented in common words. Part II required the writing of each prefix when given as the cue-stimulus a definition and a root with which to form a fairly common word. Part III was a pure test of prefixes. A definition was given of a "word" which could be constructed with the right prefix and a "nonsense" root. The maximum score was 218 points.

Three groups were used:

1. Delayed effect group (N=16). No answers printed in booklet.
2. Immediate effect group (N=15). Answers in booklet.
3. Correction group (N=13). After completing whole booklet, students returned to wrongly answered items to correct them.

During learning, slight time differences favored groups 2 and 3 over 1 (129 minutes versus 137 minutes). Absolute scores on the posttest were higher for groups 2 and 3 ($p=0.06$). The amount learned (difference between pretest and posttest) was significantly greater for groups 2 and 3 ($p=0.03$). Miss Meyer reports that this difference was due to distribution differences rather than central tendency. Only one student in group 1 (teacher scoring) delayed overnight was above the median of the other two groups.

When groups 2 and 3 were compared to determine the effect of going back over the wrong items, no differences were found.

From an examination of parts of the program to determine the effects of prompts, Miss Meyer reports that a successful method of introducing the prefix definition pairs was to present them as a "rule" in a sentence. This was revealed by an examination of the errors made. She confirms the Porter finding that context cues operated to restrict the words selected by students filling in the answer space. Sentence structure appears to be a useful constraining factor for response. She reports that syntactic prompts were effective, semantic ones less effective. The latter conclusion comes from the errors in spelling.

Miss Meyer draws some interesting inferences that have educational implications and can be studied experimentally. One is that copying an answer from a clearly designated model is not an unnecessary elementary requirement to place upon the student; she maintains that some repetition is needed. She also believes that her data imply the value of "vanishing" as a technique. This she accomplished by changing the word base from one familiar root to another and then substituting a nonsense root for use in attaching the prefix. This could be manipulated systematically by varying the language root over a range of different frequency-of-usage levels. From her point of view the root used in successive examples should be one that is less and less frequently used.

The Meyer results corroborate those of others in revealing little, if any, relationship between measures of aptitude (SRA reading test scores) and gain. The correlation was 0.09 (posttest minus pretest). Correlations with pretest, posttest and actual error scores were 0.25, 0.35, and 0.34, respectively. The pretest correlated only −0.52 with the gain score, indicating that there was a tendency for those who knew least to gain more. The best predictor of the posttest score was the error score (0.69, for all groups combined; 0.82 for groups 1 and 2, and 0.71 for group 3—all significant at 0.01 level).

Keisler (1959a) used multiple-choice methods to program the teaching of "understanding" the area of rectangles. He defined understanding operationally in terms of the variety of questions correctly answered which were different from those encountered during training. This is consistent with Pressey's (1950b) procedure for studying the "higher level" of learning produced by the punchboard.

An adaptation of the Navy's Film Rater—a filmstrip device—projected onto a viewing plate and the learner pressed one of five buttons in making his response. If the response was correct, a green light lit up, and the next multiple-choice item could be viewed; if it was wrong, a red light turned on, and the learner had to turn it off before he could try again (the correction method or pure-part procedure.) This machine automatically recorded a graph of all right and wrong answers for each response by every learner.

The program contained 120 items; the first 10 explained the method of operating the machine and the purpose; the 110 remaining items contained the substantive material to be learned. Concepts of length, width, square, rectangle, were followed by items using them—for example, finding the number of square units in rectangles—and the concept of area followed. Applications were varied and included such problems as painting and floor covering (rugs, tile) involving adding and subtracting areas, finding length and width. Examples are included in the article.

Several explicit programing features were:

1. Small steps
2. Vanishing (Skinner's system, with stimulus and prompt)
3. Promotion of critical intraverbal associations (e.g., principles and definitions)
4. Review
5. Repetition
6. Use of interest or attention-getting devices
7. Use of difficult multiple-choice forms—two, three, or four alternatives.

The students, 28 from the fifth and sixth grades, were individually matched as to intelligence, sex, reading ability, and pretest scores. They were divided into 2 groups of 14 each; the controls were given no special instruction of any kind.

Pretests and posttests were of the free recall or essay type; the former contained 12 problems involving multiplication and division plus 8 problems dealing with areas of rectangles. The posttest consisted of the same 8 problems on area and another 8 new and more difficult ones.

The experimental students used the machine for two or three periods on successive days. Total time spent with the machine ranged from 1.5 hours to 2.0 +hours. The posttest was given the following day.

The mean of the experimentals was 12.4 (SD=5.6), whereas the control mean was 5.4 (SD=3.7). A sign test revealed that all experimental students except one showed a higher posttest score than the matched control students. This was significant at the 0.01 level.

Keisler reports that the experimental group learned far less than was expected from their previous performance in learning. Total errors ranged from 3 to 118, with a mean of 54. The rank order correlation between total errors and gain (posttest minus pretest) was −0.83. The rank order correlation of MA and gain was 0.52, and with number of errors MA correlated −0.79. It is interesting to note that here a substantial correlation was obtained, although the amount learned was not high; whereas Porter (1959) and Meyer (1959) both reported zero correlation when the amount learned was high. This suggests the hypothesis that the correlation between a general ability measure (e.g., mental age) and gain may be an inverse index of the efficiency of a program. The more efficient the program, the lower the correlation between gain and ability. Keisler comments that his program was too difficult for most of the students he studied. He recommends reduction of the amount of reading required and smaller steps to reduce the difficulty of the program.

Keisler reported a progression in errors with successive blocks of 10 items starting with 5 errors on the first attempt (150 possible) and ending with 66 for the last set of 10 items. He assumes that these later items require understandings and abilities not tested for in the pretests.

Keisler offers as a third technique for simplifying the program the use of a wider variety of items on each new arithmetic process.

While learning was achieved by the experimental group through the use of both multiple-choice items and the correction procedure, the study does not indicate whether the amount obtained was more or less than would be produced by other methods. Consequently, we have no basis for knowing whether the small amount of learning was related to the program, the method, the content itself, or the fact that the students only worked with the machine for 1.5 to 2 hours.

Studies with exceptional children

Several studies have attempted to use teaching machines with exceptional children; the earliest one reported was by Ordahl and Ordahl (1915). Falconer (1959) taught a sight vocabulary to young deaf children. Audrey Longridge (1960) in an unpublished doctor's dissertation at the University of Pittsburgh used an audiotape machine to teach speech correction to children with articulation disorders. Smith (1959) has reported preliminary results from machine teaching of English to mentally retarded children. Koronakos (1960), in an unpublished study, has reported preliminary findings suggesting that different methods of teaching basic reading skills to the mentally retarded are not all equally effective. In still another set of unpublished studies at the University of Illinois, Stolurow, Hasterok, and Ferrier, and Stolurow and Peters (1960) have obtained preliminary results concerning the relative effectiveness of prompting and confirmation procedures in teaching sight vocabulary to mentally retarded children. These Illinois studies were made possible by funds from the Cooperative Research Program of the U.S. Office of Education, Project 661. Susan Meyer (1959) used an "honors group" of eighth graders in one of her unpublished studies; thus while several special education groups have not been used, as yet, there is gradually emerging an extensive set of studies which could have educational implications for groups requiring extensive individual instruction.

Ordahl and Ordahl (1915) designed a simplified typewriter-like machine which had four keys and a small display unit revealing color patches. The institutionalized retardates (N=30; CA 15–35; MA 6, 8, 10) practiced with the device under conditions that allowed them to see the keys and the display so that they could learn to press the key that matched the color of the display. The colors appeared in an invariant order, making possible the development of a serial response skill. By covering the colors and keyboard the experimenter could determine whether the subjects had acquired this skill, which included striking each key with a particular finger. They were allowed ten 1-minute trials for a period of 6 days. Performance was evaluated in terms of the number of strokes and the accuracy.

Ordahl and Ordahl found that learners with mental ages of 6 years required the most instruction, started at the lowest level of efficiency, and increased at the slowest rate. However, while their errors remained about the same, those with MA 6 increased their response output and in this way showed some evidence of improvement in the number of accurate strokes made. Only one child at MA 6 learned to perform with the colors and keys concealed.

The MA 10 group started with the highest level and increased at the fastest rate, both in number of errors and number of strokes. By the end of the third day of practice they had achieved a practically perfect score. Those with MA 8 were in between the MA 6 and MA 10 groups in their performance.

This generally positive relationship between MA and rate of gain from practice, however, has not been found by other investigators to be significant. One possible reason for this discrepancy is the relative demand made upon the limited memory capacity of these subjects. Gains represent the cumulative effects of immediate memory, and a serial learning task requires the accumulation of the associations.

Studies which do not show a positive relationship between MA test scores and gain scores have been reported by Woodrow (1946). More specifically, studies which employed programing principles that resulted in relatively high rates of learning have tended to show a zero-order relationship between these variables (e.g., Detambel and Stolurow, 1956; Ferster and Sapon, 1958; Meyer, 1959; and Porter, 1959). On the other hand, where the amount of learning has not been very great (e.g., Keisler, 1959a) the correlation tends to be larger. This is an interesting problem with important educational and psychometric implications.

The results suggest that there is a minimum general level of ability required to learn a task and that once this level is achieved the gain scores are related to specific factors. This is compatable with the findings of Fleishman and Hempel (1956) who have determined specific sources of variance in learning scores. They relate the component variance to specific aptitude measures and find that terminal scores not only have a different factoral composition than the preceding scores but also tend to consist of unique or task specific variance.

One hypothesis suggested by these data is that efficient instruction (live or machine-mediated) will lead to reduced individual differences with materials that fall within the learner's capacity limits.

Falconer (1959) reported a preliminary study with young deaf children in which he pointed out the apparent advantage of using teaching machines with these children who traditionally require a great deal of individual instruction. Very small classes are usually used in the educational program for the deaf; the teacher is frequently working with a single deaf child in the guiding of his or her language development; furthermore, much of the teacher's time is devoted to drill.

Recognizing the needs and the possibilities of using a teaching machine to meet them, Falconer designed and constructed a device which he tested by teaching word-recognition to young deaf children. He programed 15 nouns with 5-choice problems for the children. The materials were taken from a standard primary word list used with the deaf. Each of the 15 nouns was combined with a picture, and 6 different frames were prepared. Every frame contained a 5-alternative multiple-choice array. The key word represented by the picture as the cue-stimulus was accompanied by four distracting words. In this study the cue was the picture, and words were the response terms. Falconer also presented the printed word under the picture, a technique he considered a prompt. The learner's task was to match the cue with its counterpart in the array of words.

One of the rules Falconer used in programing was seldom to repeat "distractors", to avoid calling undue attention to them; another was to avoid repeated use of initial consonants in the first frame; however, the initial consonant and often even the final consonant in the key word were duplicated in one of the distractors in the second frame. Furthermore, a later frame might have two distractors with the same initial consonant as that of the key word. Still other similarities in the key word were introduced as common elements in subsequent frames. Reversal cognates and similar endings were also used to accomplish this. In this way the discriminatory task, with respect to the differentiation of response terms, was increased in difficulty; however, limits were imposed upon this so as to insure a fairly large number of reinforcements.

Falconer used 8 deaf children (CA from 6 years, 2 months to 7 years, 6 months) who were in a beginning primary class in the oral department of the Illinois School for the Deaf, Jacksonville, Ill. These children worked with the machine 5 minutes a day for 10 consecutive school days, 50 minutes in all. To determine the effectiveness of the program, a multiple-choice paper-and-pencil test of the 15 words was given. It was administered just prior to the first session at the machine; at the end of the experimental program; and a third time, 2 weeks later. The teachers carefully avoided using in class the words in the machine program during the period of the experiment.

The results indicated that prior to training, the children made slightly more than a chance number of correct responses (three correct) but not significantly more—4.12 words. At the end of the instruction they achieved an average of 13.75 words correct. The range was 13 to 14 words. When they were tested for retention two weeks later, a mean of 13.63 words was obtained. These children learned about 14 words in a total of approximately 50 minutes of practice.

Since no controls were used, no data were available to indicate whether or not this exceeded what could be accomplished by more conventional means of instruction. Reports of teachers of the deaf suggest that this rate of learning a sight vocabulary is in excess of what they normally achieve in a classroom. However, this observation should be tempered by the fact mentioned earlier that the teacher is often obliged to work with an individual child in the classroom and distribute her time among all those present. These data, however, suggest that the teaching machine might be at least as effective as a teacher who has to distribute her teaching over several students one at a time. The overall achievement level which she might secure could be significantly increased if she had a battery of machines to supplement her own efforts. In this way every child could be kept busy. Certainly the result suggests that additional work is warranted, and that extensions to drill in verbalization also should be explored. A possible use might be a motion picture sequence paired with a word to show the child the type of movement of tongue and lips used in making specific vocal responses.

Koronakos in his unpublished study (1960) compared the following five methods of teaching reading skills to the mentally retarded:

A. Picture-word; response: button press
B. Word-picture; response: button press
C. Audio-word; picture; response: button press
D. Picture alone; response: vocalization
E. Printed word alone; response: vocalization

In two separate experiments using, in separate analyses, errors and trials to criterion, Koronakos found the typical rank order of these methods of training was: E, B, A, C, D. In other words, presenting the printed word alone as the cue-stimulus and requiring the child to make a vocal response (confirmation procedure) was the most effective method of instruction. Second was the use of the printed word as a cue-stimulus with a picture as the eliciting stimulus (prompt) for the response.

The method used for group E can be called the confirmation (or anticipation) procedure, since the printed word is used alone and the learner is required to make the correct response in order to receive reinforcement or confirmation of his response. The procedure used for group B is a prompting procedure, since the word and picture are combined in their presentation and presumably the picture serves as a prompt for the verbal response of naming the word. Since the mode of response required by Koronakos was different for these two methods of instruction, they cannot be compared.

If the pictures were more familiar to these mentally retarded children than the printed words, then the fact that the printed word-picture combination (group B) resulted in the more rapid learning than the picture-printed word combination (group A) suggests that in programing it is better to have the more familiar term in the response position. This corroborates the results of Sheffield (1946) and others who have used different subjects, materials, and machines of the nonadaptive kind. It also suggests that Falconer, for example, might have obtained even better results if he had used the word-picture rather than the picture-word sequences.

While tentative, Koronakos' results suggest the hypothesis that for teaching language to mentally retarded children it might be efficient to begin a program sequence with the printed word as the cue-stimulus and require a vocal response with a confirmation procedure. The next stage might be to use the printed word as the cue-stimulus and to also use a vocal reponse but now introduce prompting procedure with a picture as the response producer. This programing sequence could then be followed by the conditions used for group A, the group that was third in rank order. Here the association reversal condition for the preceding stage would be introduced.

The resulting program would be one in which the stages are ordered so as to proceed from the easiest condition for learning to the most difficult, to insure most rapid progress and a high overall average rate of reinforcement. The more difficult combinations would be introduced in the order of the average difficulty level. Thus, this study suggests a program sequence that could be used to teach vocabulary to mentally retarded children. Obviously, research is needed to compare the suggested sequence with the various alternatives, since this is the critical part of the experiment. If the predictions are supported, then a useful general method might be suggested by the approach.

Stolurow with Hasterok and Ferrier and with Peters and Steinberg (1960 e and f) in two preliminary unpublished studies on mentally retarded children at the University of Illinois compared a prompting and a confirmation procedure. The first study used two small random groups of EMH (educable mentally handicapped) children in special education classes in the county; the second used EMH children in a residential institution. These investigators also used two different criteria of learning. In the first study, half of the children were carried to a criterion of 3 correct responses in succession and the other half to the criterion of 12 correct responses in succession; in the second, the criteria were 12 and 24 successive correct responses. In both studies words were cues, pictures were the response producers, and the correction procedure was used. The results reveal that with the lower criterion the two methods do not differ. With the higher criterion, however, there was a difference in the learning scores favoring the prompting procedure. This is at variance with the results reported by Koronakos. In addition to other factors the two different criteria employed rule out direct comparisons with the Koronakos study, in which for example, 9 words were presented 5 times a day until the criterion of one perfect trial was achieved or 30 days of training had been given and in which the correction procedure was used. In the Stolurow *et al.* studies, five words were taught each day using the correction procedure. One criterion in the Illinois studies was lower than that employed by Koronakos; the others were considerably higher. Moreover, Koronakos did not report significance tests, so that it is possible that the differences between his confirmation and prompt groups E and B were not significant.

Further research on this problem seems to be needed, particularly since these procedures are basic to much of the programing used in teaching beginning reading.

In a study of retarded children, Smith (in Galanter, 1959) reported preliminary results from the programing of English grammar for 30 seventh-grade, slow learners (IQ range 75–90). The report indicates that the preliminary results produced 90-percent correct responses.

This same program is currently being studied by Bilsky (1960, unpublished study) with children being taught in regular classes and using a programed textbook. Preliminary results indicate no differences between the groups; however, it was observed that teachers of the so-called "controls" were adopting the programed textbook procedures to teach their students.

Studies with adults

Holland (1959 a and b) at Harvard, developed and used two successive editions of a machine program based upon B. F. Skinner's "Science and Human Behavior" (1953). An error analysis of the first edition provided the data for the second edition. Harvard and

Radcliff sophomores, plus some juniors and seniors and a sprinkling of freshmen and graduate students, took the program as a college course. There were 187 students the first year and 146 the second.

In addition to errors, Holland recorded the time taken to complete the machine disks. Each disk contained 29 items; there were 48 and 60 sets of items in the 1958 and 1959 programs, respectively. With the first edition the median time was 18 minutes per disk and 14.5 hours for the entire set of 48. With the revised edition the median time dropped to 12.5 minutes per disk and 12.5 hours for the set of 60. Thus a 2-hour saving per student, on the average, was achieved in spite of the increase in the number of items (12 more disks of 29 items each or 348 more items). This indicates that an increase in the number of items in a program does not necessarily mean an increase in average time for completion.

One disk, in both editions, required as much as 20 minutes to complete on the first cycle; one took as little as 8 minutes. The fastest student took only 7 hours and 42 minutes for the set of 60 disks; the slowest took 26 hours, 20 minutes. This seems like a wide spread of individual differences, and one wonders whether it might not be reflecting the effects of a large number of uncontrolled variables, since the instruction extended over a whole semester.

Holland did not find evidence of a difference in the number of items correct for students who spaced their practice as contrasted with those who massed their practice.

Blyth (1960), at Hamilton College, programed college logic for use in his Visitutor, which accommodated 1 foot of film at a time. He found that with the items in a programed textbook form, the Hamilton College students took from 5 to 10 minutes to complete 40 items; the average student made one error per lesson. He also observed that the students who studied with the programed material showed less variability than those taught by conventional means. No data on direct comparisons have been reported, however.

Day (1959), at Ohio University, used a "scrambled book" format (Crowder, 1959) to teach the kinetic theory of gases to his college classes of general chemistry and physical chemistry. He divided each class in half; one half used the book, and the others learned by conventional means. In comparison with the controls, the experimental group scored 20 percent higher and made about one-fourth the number of wrong answers on the midsemester examination.

Ferster and Sapon (1958) at Harvard, applied Skinner's programing principles to the teaching of German. To implement the teaching they used a cardboard overlay that had a notch cut out in one corner. This overlay was used by the student to mask the printed page so as to expose one item at a time. After writing his answer, the student moved his template down to expose the correct answer; by moving the cardboard down some more, he exposed the next item.

The program introduced new things one at a time (minimal change) and contained an item series that was graded in difficulty from easy to hard. Of the 17 graduate students who volunteered to take the course, only 6 finished. Their mean time was 47.5 hours for the equivalent of a semester's work. Normally this course took a student 48 class hours plus 96 homework hours to complete.

Evans, Glaser, and Homme (1959) at the University of Pittsburgh conducted two preliminary studies using the programed textbook format they developed. In the first study they first wrote a 51-step program on "Conversion to Number Bases Other Than Ten", and then wrote variations of it by either deleting or adding items so as to produce four versions of the following lengths: 30, 40, 51, and 68 steps. Four independent groups of five graduate students in education were given these sequences. Each student took a written test after he completed the sequence. The results indicate that "smaller" steps, i.e., the use of more items to cover the same subject matter, were associated with significantly fewer errors on immediate and delayed written tests. Smaller steps also were associated with less time per step and fewer errors during learning. That there probably is a point of diminishing returns in granulating a program is indicated by the scores of group D (68-step sequence) which were slightly below those of group C (51 steps). However, this difference could be due to a sampling error, since group D was not set up at the same time as the other three groups.

In the second study these investigators used two groups of undergraduates and a sequence called "Fundamentals of Music." One group, W, went through the sequence in the usual manner—writing one or more answers to each step. The second group, N, went through the same material but was instructed not to make overt written responses. Of interest to a disciple of Dewey was the finding that group N—no overt response—did better, though not significantly so, on the test given afterwards. Group N also took less time to complete the program. This finding suggests that it might be useful to reexamine procedures that require overt written responses. Furthermore, this requirement of elaborate overt responses has expensive implications for the design of teaching machines.

Kaess and Zeaman (1960) examined the problem that emerged from the second study which had been published earlier by Porter (1957) and Skinner (1958) who disagree with Pressey (1950b) regarding the importance of making a physical response as a way of providing critical feedback. Porter, for example, emphatically states that unless a device requires an observable response, it is not a teaching machine but simply a teaching aid. Porter and Skinner also assume that the best learning situation is one in which the trainee is always or nearly always correct. For different reasons they object to the punchboard and multiple-choice items as a method of programing. Porter is concerned about the "conditioning" of incorrect responses and presumably the need to extinguish them; Skinner feels that wrong response alternatives are out of place in the process of shaping behavior, for unwanted forms are reinforced.

Kaess and Zeaman (1960) conducted two experiments. They used a booklet containing 150 multiple-choice items and an IBM answer sheet stapled to a cardboard template that provided immediate knowledge of results. The items concerned definitions of psychological terms and the five trials differed from one another in the random sequence in which the same 30 items were experienced.

The independent variable, "amount of negative information," was manipulated by varying the number of item choices available to the learner on the first trial. In condition 5 there were thirty 5-choice items; in condition 4 there were thirty 4-choice items, etc. for conditions 3, 2, and 1. A punchboard type of arrangement with the IBM answer sheet could provide immediate knowledge of results. The control condition, 5 NC (no correction on trial 1) used a modified punchboard, a solid template behind the answer sheet. On trials 2 to 5 they used the punchboard and received immediate knowledge of results.

The second experiment related to the problem of the reinforcing value of punching on a punchboard. In this experiment, booklets for the first trial of conditions 1 and 5 were modified by underlining the correct answer with a red pencil. Here the students merely noted the alternative that was underlined, since it was the correct answer. The students did use the punchboard on trials 2–5. As a contrasting condition another group of students was told to punch answers on trial 1. A comparison of the performance of those who on trial 1 received immediate knowledge of results with those who did not was very revealing. On trial 2 those who had previously received knowledge of results clearly made fewer errors than those who had taken the items as a test.

"Negative knowledge" is received when the learner punches an answer space to signify his choice and finds out it is wrong. All learners received the same amount of positive knowledge, since they used the correction procedure. According to the authors, the data reveal that the more negative knowledge a group is given, the more errors it makes ($p<0.001$). Evidence was obtained for the hypothesis that item difficulty may be related to the effect of negative knowledge—that negative knowledge had no effect on easy items, but a strong effect on hard items.

While Pressey and his students used the punchboard only once for a set of materials, Kaess and Zeaman used it repeatedly. They examined their error curves to see if the two types of knowledge, positive and negative, were related to rate of error elimination. The groups ordered in terms of rate of error elimination were 5, 4, 3, 2, and 1, from fastest to slowest. That negative knowledge is strongly resistant to correction was revealed by the generally higher level of errors produced by group 5. The learner, given five alternatives to choose from, rapidly reduced his errors over subsequent trials but soon leveled off above the other groups.

These data relate to the early work of Pressey (1950b) on the best number of alternatives to use. Pressey argued for the use of four alternatives as against just two (e.g., true/false) in terms of difficulties experienced in preparing more alternatives and the failure of the true/false dichotomy to discriminate. Kaess and Zeaman's data based upon repeated trials and error-elimination rates provides a basic set of new data arguing for fewer alternatives.

The relative importance of covert and overt behavior is a fundamental problem in learning. In comparing selected groups from the two studies, the authors suggest the following hypothesis: Reading a correct and an incorrect answer, when the former is underlined and the latter is not, results in the formation of an association that is not remembered in the case of the wrong response. On the other hand, if the learner punches his wrong answer into a board, the associative connection between that response and the cue-stimulus is stronger and, although it may be eliminated on subsequent trials, it is nevertheless remembered better and harder to eliminate.

In summary, these investigators found that the rate of learning definitions of psychological terms by means of multiple choice discovery of the correct alternative varies inversely with the number of available wrong alternatives when overt error responses were made (when the learner punched holes) but not when the wrong answers were merely read. This result may be explicable in terms of the amount of associative strength formed under the contrasted conditions: with overt response the associative strength could be greater, wrong responses consequently harder to get rid of. While the first experiment lends support to the Skinner-Porter position, the second experiment says that negative reinforcement does not necessarily impair performance when the learner merely reads a wrong answer. It also provided evidence that reinforcement of overt correct responses is no more effective than the reinforcement of covert performance in producing correct responses.

Evans, Glaser, and Homme (1959) conducted three other studies of interest. In these they evaluated sequence learning and textbook presentation of the same material. In one study 17 undergraduates were given 10 pages of standard statistical text; a second group of 16 was given a programed text covering the same material. After each group finished they were given a multiple-choice test. The second group obtained higher mean performance scores but without significant difference; however, the group who studied the programed textbook showed significantly less variability in their scores.

The fourth study used a revision of the test employed in study three, one that included short answer items to make it more difficult and supposedly more discriminating. Two new groups were given the same materials, and the learning sequence group again obtained a higher mean performance score. The difference approached a minimum significance level more closely but did not attain it. The significantly smaller variability prevailed for the programed textbook group.

It seems that programing tends to produce homogeneity or reduce individual differences more than conventional textbook material. This may be a factor contributing to the drop in correlation between general ability measures and scores on programed materials (e.g., Detambel and Stolurow, 1956; Meyer, 1959; and Porter, 1959).

In the fifth experiment the same design was used as in experiments 3 and 4, but the subject matter was "Fundamentals of Music". In this experiment the group using the programed text performed significantly better ($p<0.05$) on a test of identification of musical notations. Here, too, they displayed less variability in their scores.

Hatch (1959) used a card device developed by the U.S. Navy Training Devices Center to teach instrument flying information to pilots who worked with the device voluntarily while waiting to fly. He used three groups: (*a*) A device-player group; (*b*) a device-nonplayer group; and (*c*) a no-device group. The N's were 43, 15 and 36, respectively. He reports that the self-tutoring experience resulted in statistically significant gains in job information. Probably the most important finding was the difference between the experimental and control groups ($p<0.01$). The practice effect (differences in test scores) was significant, indicating that the experimental group learned from the machine.

These studies of programed learning using a variety of materials and methods of implementation as the sole source of instruction corroborate and extend the findings previously reported on teaching by machine as only one of several instructional methods. Again both children and relatively experienced learners benefited from a programed instructional device. These devices not only tend to produce performance which is freer of error than conventional methods of instruction, but they also reduce the amount of instruction time required.

SPECIFIC PROBLEMS

Ability, aptitude, and individual differences

Several studies have dealt with different problems relating to ability or aptitude and individual differences in performance either during instruction or on a separate test following programed instruction. Two basic problems seem to be most salient in the studies thus far reported: One is the question of whether aptitude, as measured by conventional tests, correlates equally well with performance on a programed sequence and with scores earned through studying by other means; the second concerns the range of individual differences in performance on a test after instruction through a teaching machine as contrasted with more conventional means.

Porter (1959), working with sixth graders, found that the correlation between IQ and achievement was significant and positive for the control group (0.343) but insignificant and negative for the experimental group (−0.128, essentially zero).

Ferster and Sapon (1958) found that scores obtained by adults with their programed German translation materials correlated less with aptitude measures. The battery of language aptitude tests used was one originally developed at Harvard and validated there, therefore appropriate to use with the experimental subjects. The correlation (rank order) between the aptitude scores and mean achievement scores was essentially zero.

Detambel and Stolurow (1956) found that the relationship between both language and quantitative subtests of the ACE scores (American Council on Education's Psychological Examination for College Freshmen) and performance or a programed task became insignificant. Their data are based on 302 University of Illinois students divided into five ACE groups according to their Q-score (quantitative score) and again according to their L-score (linguistic score). The number and percentage of students in each ACE quintile group who correctly performed on all 27 items were found, and the quintiles at which the programed sequence produced a significantly different percentage of perfect performers was determined. Seven items exceeded the minimum confidence level of 0.01, and all 7 were obtained in the first three quintiles. In no case was there significant difference between the proportion of 100-percent performers at the highest quintiles under the two sequences. These data demonstrate that at the low ACE levels, a random sequence produces a significantly smaller proportion of 100-percent performers than does the sequence produced by the minimum-change principle. However, at high ACE levels the two sequences do not result in significantly different proportions of 100-percent performers. Further evidence of the relationship between ACE scores and performance under the two sequences is revealed by the rank orders of the quintiles: with random sequencing they tend to correspond perfectly (with one exception in the case of L-score) with the rank order of the percentages of the 100-percent performers.

Under the minimum change principle of sequencing materials, students at all ACE levels were about equally successful in learning. Under the random arrangement of items, however, there was a positive correlation between scholastic aptitude and percentage of 100-percent performers. At low ACE levels there were significantly fewer 100-percent performers under the random procedure for sequencing than under the minimum-change procedure. However, with the random sequence the students at the top ACE levels were about as successful in learning as those under the minimum-change condition at all ACE levels.

These data suggest the hypothesis that a significant interaction may be found between aptitude level and programing.

Freeman (1959) reported a trend in his data to the effect that lower-ability college students benefited more from the reinforced practice provided by the punchboard than the higher-ability students. In his study only practice opportunities were given, and his results were not statistically significant; but the trend did appear.

Increased homogeneity of scores on the test following training with a teaching machine have been reported by Glaser, Homme, and Evans (1959) and by Homme and Glaser (1959a) in several separate studies. These data were obtained with college students who used a programed textbook.

Little (1934) using educational psychology subject matter on college students, reported that one of the most interesting findings was that slower students profited most from the use of teaching machines. This was revealed by comparisons of quartiles between the drill group and the control group. For example, with the first quartile, the drill group was 19 points above the first quartile of the control group, whereas for the third quartile there was only a five-point difference between the two, with the drill group above the controls. Furthermore, the first quartile of the drill group was 7 points above the median for the control group.

It is interesting to note that Pressey (1926) was impressed with the discovery that the use of multiple-choice items (e.g. 4 alternatives) could, for a set of 10 items, yield an error score from 0 to 30 rather than from 0 to 10. In this connection Pressey comments, "It is possible for the subject to make more than one mistake on a question—a feature which, so far as the writer knows, is entirely unique and which appears to increase decidedly the significance of the score." (p. 374)

This early observation implies an expectation of greater individual differences resulting from the use of the multiple-choice type of item in the teaching machine. Contrary to this expectation, however, the existing research results suggest that, if anything, efficient methods of programing tend to make for a more homogeneous grouping of learners. Individual differences are reduced rather than magnified.

One other set of data in support of the reduced range of individual differences resulting from the use of teaching machines are the data reported by Briggs (1949) showing that more of the students who studied with the punchboard device earned more A's and B's in the course than did those who did not use the device. Pressey also reports that in a study with an "examination credit group" who received little instruction and took mostly punchboard drills at an accelerated pace, 67 percent received A or B grades. Jensen (1949) reports similar data. His results show that 51 percent of the students in the independent study laboratory received A's, in contrast to 10 percent of the students in the regular section of the class who received A's; 13 percent of the laboratory students received B grades and 33 percent received C grades; there were no D's or E's.

The data suggest two important trends to be verified and developed further by future research. The first is that aptitude differences tend to lose their predictive value when more efficient methods of teaching are employed. Consistent with this finding is the observation from a variety of sources that individual differences tend to be reduced with teaching machines. The tendency is for the lower-ability individuals to achieve more, and thereby to become more like the higher-ability group in their performance on the programed learning course. Both findings have been reported by a number of studies suggesting that they may have real significance.

Task factors

Pressey (1950b) has reported data relating to the effect of length of the learning task on performance. He found that a short program (30 to 40 items) used frequently is better than a long one (approximately 100 items) used occasionally.

Severin (1955) studied a number of factors, among which were the effects of differences in subject-matter (a Russian-English vocabulary). As a paired-associates task Severin's data suggests that both the Russian vocabulary and the English vocabulary were equally well learned when two- and four-choice alternatives were used. This result was obtained with a recall test given at the end. He also compared four pairs of items with items that had a question and four alternatives. Statistically significant effects were obtained, favoring the four pairs.

Kaess and Zeaman (1960) also found evidence for the effect of number of choices on the error performance of their subjects.

Stephens (1953) worked with more than 1,500 Ohio State University students in studies involving the punchboard and the drum tutor, which were used with 30 multiple-choice questions. Materials consisted of nonsense syllables, easy Russian vocabulary, difficult English vocabulary, and educational psychology; thus, all materials were of paired-associate or one-to-one type. He used the correction method ("retained situation") and the "vanishing situation," or the noncorrection procedure.

Among other things, Stephens was concerned with the meaningfulness of materials being learned. He reports that the more meaningful Russian and English showed higher rates of learning than did the nonsense syllables. This is an ambiguous finding in the sense in which it is presented, since a Russian word is not likely to be any more meaningful than a nonsense syllable. However, the Russian words are more likely to contain trigrams (three-letter sequences) which are common in English. Consequently, these letter patterns, being more familiar, are likely to be learned faster than the less frequent nonsense trigrams. Secondly, as a contributing factor to increased rate of learning, it is possible that the meaningful English response terms used in teaching the Russian vocabulary were effective in producing more rapid learning, since these terms were already familiar to the learner. With the nonsense materials, however, the response terms were relatively unfamiliar; consequently, this task required response learning as well as discrimination learning and associative learning between the cue-stimulus and the response.

Pressey (1950b) compared variations in material from trial to trial with the repeated use of the same material. He found that changing the relatively less meaningful Russian vocabulary handicapped the students, but in the case of the more meaningful English vocabulary there was no difference between the groups given the varying material and those given the same material.

With respect to these task factors the limited number of studies suggest that task length and meaningfulness may make a difference in learning rate. Response limits in terms of the number of alternatives also seem to be important. The data tend to corroborate those obtained with studies in which teaching machines were not used.

Practice factors

Of the three general classes of factors (subject, task, and practice) the practice factors have been most extensively investigated in research with teaching machines.

Pacing factors, particularly with respect to the rate of presentation of material, immediately suggest themselves as possible contributors to the difference in performance in teaching machines. One of the measures of an adaptive teaching machine is the extent to which the machine waits for the learner's response. This seems to be an appropriate and useful feature of a teaching machine which, superficially, at least, would justify any added expense. Research by Briggs, Plashinski, and Jones (1959) considered this problem. They used two groups, each of which was given 13 minutes of practice on a 20-item paired-associate learning task. One group was allowed to pace itself; the other was paced by machine. They found no differences for the two methods. It is interesting to note that they used a paired-associates learning task in view of the fact that this type of task is generally considered to be less sensitive to the effect of distribution of practice. A more sensitive type of task would be a serial learning task, a stable cue-stimulus sequence. It is hoped that future studies will expand on the present limited data by using a range of paced conditions rather than a single temporal unit.

Correction versus noncorrection procedure

Several investigators have examined this procedure. With the correction procedure the machine is designed so that it represents the original item until the learner makes a correct response. Both Pressey and Skinner have incorporated this feature into their devices and, more recently, Stolurow and Porter have built it into a machine which they are using. Crowder's Autotutor and the scrambled textbook also use the correction method. Briggs (1949) compared the use of the punchboard with correction procedure and its use without it; essentially this was a comparison of the pure-part method with the whole method, in that with the correction procedure the individual is required to master an item as a part before he is allowed to proceed to the next part. On the other hand, with the noncorrection procedure, the individual is required to make a response and go on to the next item whether or not his response is correct. Thus he goes through the whole set of parts, then returns to the beginning and starts over again, repeating the procedure until all of the parts have been learned. Briggs reported that the pure-part method, or correction procedure, was superior to the noncorrection or whole method. Both methods were superior to the regular test procedure in which the learner was given no knowledge of results.

Bryan and Rigney (1956) made a comparison similar to that reported by Briggs. These investigators used 48 senior NROTC (Naval Reserve Officers Training Corps) students. They used the tear-a-tab device in which the learner pulled off a tab which he thought contained the correct alternative. One group of students served as controls and answered the items in the usual way, whereas a second group was given immediate knowledge of the correctness of their response by finding under the tab a "right" or a "wrong"; if wrong, they were required to continue selecting answers until they located the right one. A third group was the same as the second, with one important exception: for them, explanations of why each alternative was right or wrong were printed under the tab opposite the alternative.

All groups received 150 items; they were retested on a multiple-choice criterion test one week after the training session. The primary difference found was in favor of the group getting the explanations.

Irion and Briggs (1957) used the Subject-Matter Trainer and compared a variety of modes of operation. The single-try mode of operation (noncorrection procedure) was the poorest of the methods used; the practice mode was better. This is the correction procedure, the mode in which a buzzer is sounded after each error is made. The learner makes any number of errors, but when he finally makes the correct response a green light goes on, and he proceeds to the next item.

The Irion and Briggs study demonstrates that the correction procedure is more effective than the noncorrection procedure. However, although in this study the "quiz mode" was found to be the best of all methods, it does not quiz the learner in the usual sense. Rather, in this method of operation the learner merely reads the item and presses a special button, which shows a green light next to the correct answer. This is the prompting method, for the green light signifies the correct alternative. The student then presses the correct answer button and is permitted to go on to the next question. That this is the best method is particularly perplexing in view of the general speculation and discussion about the reason for the effectiveness of teaching machines. Advocates of machine teaching have attributed a great deal of their effectiveness to the Socratic method, the method of qestioning the learner and waiting for him to answer. If this finding can be generalized it suggests that the use of questions should not create a false impression; namely, that waiting for a response is an optimum procedure. The interval between cue-stimulus and response may be critical. A prompt can shorten the interval and may account for the superiority of this mode of operation. In much of Skinner's programing, for example, the material is not presented in question form: in fact, the blanks are inserted in various places in declarative statements. The material which surrounds the blank usually contains sufficient information for the correct response. This condition could be appropriately described as a prompting condition. Consequently, it appears that the effectiveness of the teaching machine may lie not in the question-and-answer type of relationship but in the extent to which the material to be learned is granulated into small steps in some way designed to get the learner to respond promptly and correctly to the cue-stimulus.

Next to the quiz mode in effectiveness was the modified quiz mode. Here prompting also is involved. In this mode of operation the student is allowed to make one, and only one, choice. If his response is correct, the green light goes on; if the response is incorrect, a buzzer sounds and a green light goes on next to the correct answer: a prompt. Thus only one response and no more than one error can be made before the student is shown the correct answer. This procedure which both prompts and limits the amount of error, was second in effectiveness. As a training procedure it was better than the "practice mode," the correction procedure in which many errors may be made before the correct response occurs.

Irion and Briggs suggest four reasons for the superiority of the quiz mode:

> 1. No time is lost searching for the correct response, therefore more trials are accomplished per time unit.
> 2. Overt wrong responses are avoided, although covert wrong responses are possible if the student fails to follow directions precisely.
> 3. There is never any signal, buzzer, or red light for a wrong response.
> 4. There is a close temporal continuity between presentation of the stimulus and appearance of the green light.

This mode of presentation should be investigated further, for if it proves superior in future studies the implication for teaching machine design would be that relatively simple devices might be very effective.

Mode of response

Coulson and Silberman (1959b) used a portion of the material prepared at Harvard for the elementary ~~psychology~~ course (the first 104 items of the course). They had a group of 80 students, 10 per condition, and each student worked for approximately two hours over a period of one week. After training they gave the students an examination which ". . . was not closely related to the material taught with the teaching machines" (p. 5). They compared the following conditions:

1. Multiple choice versus constructed response
2. Small steps versus large steps
3. Branching versus no-branching.

In the first comparison possible alternatives were provided as answers for every item, to make up the multiple-choice version of the program. Coulson and Silberman eliminated selected items of the 104 to make a "large step" deck of 56 items to implement the second variable. To make the "branching" program, they added on the backs of certain cards, instructions telling the learner what cards to omit if he responded correctly. The so-called "conditional skip cards" consisted of items covering the same concept as covered by the first item in the series. The small-step branching program included 13 branch items and 39 conditional skip items, while the large step branching program included 12 branch items and 22 conditional skip items.

The program produced a significant improvement (experimental minus control group) of the concepts taught. A test three weeks later revealed that the students retained what they had learned.

Coulson and Silberman found that: (*a*) Small step program (more items per concept) resulted in more learning, but significantly greater training time; (*b*) branching did not produce significant differences, but when they took into account both amount learned and required training time the differences favored branching; (*c*) response mode (multiple choice versus construction) did not make a difference; and (*d*) response mode and branching interacted.

These data tend to support one of Skinner's notions regarding teaching methods, namely the importance of small steps in writing items. However, the data indicate that size of step may not be as appropriate a description of what is involved as redundancy would be. It appears that the small steps are really additional items relating to a particular concept. The question involved here is whether the items in question say the same thing in a slightly different way, or whether they say something different.

On other points, however, Skinner's position is not supported. While the differences were not significant, branching was better than no branching and the multiple-choice mode of response was better than the constructed response. Two points appear to be involved here. One is that any set of notions about programing is a combination of rules for manipulating materials, some perhaps useful and others not. The utility of each should be evaluated both in isolation and in different combinations before its value can be decided. The second is that with adults for whom writing is an overpracticed or at least highly practiced skill it may be unnecessary to require a constructed (or written) response. If, however, an adult is learning a new language, a constructed response may be necessary. A child, on the other hand, has to learn to write and spell and may need a constructed response.

SUMMARY

The research reported thus far is more provocative than definitive. In dealing with it, some tentative statements have been made, to provide a basis for hypotheses that might be useful for future research.

It is clear that a variety of persons, from mental retardates to gifted graduate students, can learn from teaching machines. It now seems time for a concerted effort to tease out the factors which determine the effectiveness of instruction. Through specific investigation of variables this can be done; modern research designs and analyses of variance can be used to determine not only the main effects of such factors but also the interactions, if any, which occur. In fact, from a decision theory point of view the interactions of variables are the most important, for they would tell the different decisions required for specific conditions, for particular types of information, or for particular learners. Thus future research could be based upon notions from other sources in addition to modern learning theory and a new theory of teaching would be emerging. Research could contribute to such a theory by the systematic study of variables important in tutorial instruction by means of a teaching machine.

CHAPTER VIII

Implications for Education

TEACHING MACHINES appear to be here to stay. They have many important implications for the future of education, some related to the teaching process and the teacher, others to the school as an organization (including its personnel and physical facilities), still others to the effects upon students.

TEACHING

Teaching machines may eventually provide the basic data for a new theory of teaching, the missing counterpart of the theory of learning. It is anticipated that the machine, as a controlling device, will serve to eliminate the effects of extraneous variables and permit the identification of basic variables and their interrelationships. In effect, the teaching machine is an educational laboratory. It can do for education what physics, chemistry, and psychology laboratories, for example, have done for their areas. The variables of interest can be manipulated in a rigorous way, conditions can be standardized, etc. The machine can provide information about methods of teaching free of uncontrolled variations due to differences among teachers. Once the basic variables in the instructional process are identified, they can be studied in relation to social and personality factors.

The teaching machine seems to be a major breakthrough in education comparable to the book, radio, and television. Its potentiality needs to be explored and efficient and effective means devised for making it available. It can maintain the optimum conditions of communication and control considered essential in modern learning theory. Although mass media communicate effectively, they do not control; they are "open loop" systems. This means that for rapid modification of the learner's behavior systems they lack the critical feedback ingredient. The teaching machine, on the other hand, is a closed loop system which does provide feedback.

Skinner (1954) indicated that one of the most serious criticisms of today's classrooms is the relative infrequency of reinforcement. Many students, he points out, are dependent upon one teacher for knowledge of results; consequently, the total number of opportunities for the teacher to reinforce knowledge is quite limited. One of the places where these inefficiencies reveal themselves most dramatically is in so-called drill subjects like arithmetic; children typically fail to learn arithmetic quickly and never do achieve a high level of confidence in their knowledge and/or skill (Skinner, 1954). Skinner also points out that with current methods of instruction the symbols of mathematics have become standard emotion-provoking stimuli. The teacher is usually no happier about this than the student and is inclined to avoid the drill subjects to talk about material of greater inherent interest. Skinner asks why the classroom should be less automated than the family kitchen.

Fry (1959b) has reinforced the statements of Skinner and has pointed out some of the prime difficulties of current teaching aids such as motion pictures. Neither the rate of presentation nor the amount of repetition is varied to suit the individual's needs; they are not adaptive. Particularly since these devices are used with groups they also must be too slow for the fast student and too fast for the slow one. Fry agrees with Skinner that the teacher has been outmoded as a device for rewarding the learner, but in his view there is no danger of the teacher's being replaced by teaching machines, for although some subjects might be taught better by machine than by a live teacher, there are other subjects which the classroom teacher can present much more effectively.

Fry points out the implications of teaching machines for progressive education. The machine not only substitutes reward for punishment as a main incentive, but it also requires student participation and elicits mental activity. The machine is exceedingly versatile; the program can be designed to fit the most rigid requirements of the conservative educator who stresses "mental discipline"; it can be either factual or thought provoking; it can include logic or rote drill.

Fry also indicates the implications which teaching machines have for objective research in education. They allow for more convenient investigation of method problems at different stages of the development of the programs. Furthermore, the data collected tend to be freer of the variations produced by different teachers, and thus a more precise check on the effectiveness of the variables can be obtained.

Blyth (1960c) has pointed out an additional contribution of the teaching machine as a means of achieving more adequately than possible heretofore the democratic ideal in education. The machine has equal patience for fast and slow learners. It responds in the same way to the poor and the rich, to all races, creeds, and religious groups. Furthermore, with mass production techniques, it could extend education to illiterates and outlying groups who otherwise might not have the benefit of education. While increasing the efficiency of instruction it could also make it more economical.

TEACHER

As early as 1926 Pressey pointed out that education was at present the most inefficiently carried on of any large-scale undertaking in this country (p. 376). This, in his view, was due largely to a cultural barrier which prohibits the application of modern technology to the teacher's problems. Conservatism in the profession and the fact that teachers were relatively cheap were said to be contributing factors. In his view the introduction of automation devices would free the teacher for ". . . her most important work, her developing in her pupils fine enthusiasms, clear thinking and high ideals" (p. 376). In a later paper Pressey, (1932, p. 672) points out that labor saving is not only legitimate in education but it also may become an economic necessity. Since education is a large-scale industry, it should use quantity production methods. By this he did not mean the mechanization of education but rather the freeing of the teacher from clerical duties and drudgeries to enable him to give his students more adequate guidance in learning.

Teaching machines are not devices for eliminating the teacher (e.g., Barlow, 1960); rather they are a way of implementing his instruction and of multiplying its effectiveness. They take some of the drudgery out of the teacher's job; for while the teacher is still the responsible planner of the learner's instruction, he is no longer tied to the specific detail of instruction and drill. This routine aspect of his job can now be carried out by machine. The machine, in this way, allows the human teacher to plan and determine individual needs (e.g., Blyth, 1959c; Skinner, 1954; Stolurow, 1960 a and d). He can develop new and more efficient methods of instruction and can keep the content of the course up to date. He can plan programs to meet individual needs and spend more time getting to know his students and his subject matter.

SCHOOL

Ramo (1957) has probably been the most imaginative in conjecturing about the impact of teaching machines on the future of education with respect to its physical plant and management procedures. In the school of the future, as Ramo sees it, the child would possess a "charge-a-plate" identification unit which would be inserted in a machine to identify him and to locate his records throughout his educational development. The typical schoolday would consist of a number of periods spent, as now, in rooms with other students and a teacher; however, some periods would be spent with the machine. The machines might or might not be attended by a human operator, depending upon the particular needs of the student or the inadequacy of the machines. Even in the classroom learning situation, which would involve not only a human teacher but also motion pictures and television, there would be programed questions which would require the student to respond by pushing various keys (e.g., Carpenter *et al*, 1950). In this way a student would always be an active participating learner rather than a passive receiver of information and with a machine would be constantly in touch with the teacher.

When the student is alone in front of a machine-tutor he is equipped with controls that permit him to see animated films and other aids which should contribute to his learning. In such an ideal situation, he is completely on his own and can pace the material at whatever rate he chooses. In this situation, as in the classroom of the future, he is constantly required to respond to questions. The machine is prepared to take a principle and go over it from time to time, with altered presentation and additional detail, as required, and even possibly to switch to alternative methods of presentation, all available in its library upon request. Ramo envisions all of this to be backed up by a whole new industry.

Staff

With respect to school personnel, this revolution in education would mean that high school teaching staffs would include educational analysts, specializing in various subjects, who would review student records on an individual basis. They would be constantly seeking to discover problems and needs for special attention through direct contact with teacher and pupil. They would diagnose information and difficulties and make recommendations for improvement. Thus the school would become partially transformed into a guidance center with a minimum of routine assigned to the teaching staff. The staff member, as a consequence, would be elevated to the role of thinker and planner, using his highest intelligence and skills. Teachers would provide the essential educational functions. Ramo envisions a new type of educational specialist, the "teaching engineer," an engineer concerned with educational process and with the design of machines as well as with the design and programing of instructional materials, a person for whom knowledge of computer operation and programing would be essential.

With respect to the school changes, Fry (1959b) indicates that an automated studyhall or library is likely to be an important part of the school of the future, just as the chemistry laboratory, the machine shop, etc., are important components of today's schools. The student would be likely to carry home a small machine, at least a punchboard, to do his homework since it is a convenient pocket size and more effective for teaching. The textbook might be different, too, perhaps a programed text, cut-back page programmed book with separate answer sheets, or a scrambled textbook (" Tutor Text").

Student

The student of the future is hard to imagine. Since the industrial revolution, man seems to have learned to live with and derive benefit and pleasure from a wide assortment of machines; the need to learn to use different types of machines seems to be accelerating. A new profession, that of the human engineer, has developed to meet the challenges of this need. It is the human engineer's job to work with the hardware engineer at the design stage so as to make the demands upon the operator and the maintenance personnel minimal; thus machines are not designed to require three arms, or eyes in the back of one's head. Similarly, the teaching machine will be designed to be used by students. The demands made upon the student will be minimal and determined by educational objectives, e.g., the need to learn to write.

If machines are widely used, the student may learn to study by himself and to play and work with others; thus an important separation will be achieved. After all, what symphony was written by a group? What scientific theory was the product of a group? While groups have a very important place and students need to learn to get along with others, one might ask whether this should be done in the same setting as the learning of mathematics, chemistry, etc. Might it not be better for the student to study alone and to use what he has learned in a group setting?

Fad or Fixture

Many educators wonder whether these machines are just an educational fad. The answer to this question is obviously a matter of opinion and not one of fact, since evidence will have to be accumulated for several years to come. Certain facts argue for the possibility that teaching machines might be more of a fixture than a fad. Not all mediums of education are equivalent; the machine has certain advantages over a book. It is the most controlled of all teaching conditions; and it is designed, when properly accomplished, to take the learner from a state of lack of knowledge to full knowledge in such a way as to suit his individual needs. A conventional textbook does not always do this. In fact in serving several purposes, or masters, it must compromise each to satisfy all. The book is efficient for storing and making conveniently available large amounts of information; it has primarily a storage function and an access function. While it can be prepared so as to perform a fairly efficient teaching function as well, doing this appears to make less efficient use of space, and the result is a bulky and cumbersome device; then it is no longer performing the storage and access functions so efficiently. The teaching machine, on the other hand, serves a single purpose: teaching.

Most mass media suffer from their failure to make specific cues and responses clear (display function). In their typical format they do not require overt response; this is associated with the deficiency of eliminating the feedback loop, which informs the learner of his own progress. The teaching machine, on the other hand, displays one item of information at a time and makes salient the critical cues. Also, if the learner fails to understand a point, he can repeat it before going on. The machine also requires or makes almost mandatory some form of response before correct answers are supplied. With a teaching machine, the learner is in control, in that his responses determine what he does next within the preplanned limits of the program; thus there is feedback and adjustment of the learning situation to the needs of the individual.

Not all media are equivalent for educational purposes; they are designed to serve many functions besides that of education. The teaching machine, on the other hand, is designed specifically to teach. It introduces controlled communication, which the other available media do not. Thus it appears to be a potential fixture in the education system and not just a fad. Its problems are those attendant upon anything new; it takes time to learn how to derive maximum benefit from its use with minimum difficulty in programing.

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